Lidar Digital Materialities

Giulia Belloni – Dphil Candidate
School of Geography and the Environment
St Hilda – Oxford University



Abstract

This study explores the implications of post-smart urbanism on digital mapping, with a specific focus on autonomous vehicle perception systems, centering on Lidar technology. By analyzing visual materials from industry stakeholders, it bridges the gap between engineering and cultural geography, examining the cybernetic landscapes shaping contemporary urban areas. The research critically evaluates the role of Lidar imaging in supporting an algorithmic imaginary and addresses black-boxing issues through media archaeology, filmic analysis, and a materialist examination of Lidar data elaboration. Additionally, it scrutinizes Lidar-informed spatial and temporal dynamics, highlighting potential risks associated with crowd analysis applications. Framing Lidar imaging within the context of driverless car development and urban digitalization, the study charts the discourse surrounding Lidar, analyzes the relationship between data collection and visual representation, and describes spatial and temporal constructs generated by Lidar imaging production and deployment. Methodologically, it circumvents issues of secrecy by creating an archive of ephemeral online Lidar imaging appearances, conducting content and discourse analysis, and employing video analysis to reconstruct hidden spatial geometries and temporal modulations. By positioning Lidar sensors as optical machines shaping data flows, this research contributes to geographical debates within surveillance studies, critical data studies, and the image-data complex, shedding light on issues of control and discipline within data governance.

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Chapter 1

Beyond Coordinates:

Setting Sails through Algorithmic Waves

1.1 Introduction

Like geographers such as Cosgrove (2001; 2005; 2006; 2008), Farinelli (2003; 2009; 2016), and Olsson (1991; 1998; 2007), I contend that cartography transcends the mere act of creating maps. The practice of cartography encompasses both profound and superficial sides of our culture, while establishing a *horizon of intelligibility* that shapes possibilities for action, thought, discourse, and even perception[1].

My exploration of Lidar imaging began somewhat serendipitously. Prior to this, I had spent the summer experimenting with rudimentary sensor sets and devices like Arduino, playing with the electrification of the human body to generate novel forms of art. These creations, characterized by their cold and digital nature, possessed a unique vitality. It was during this period that Lidar imaging captured my attention, resembling an ancient flame

[1] The concept of *cartographic reason* encompasses the ways in which maps and cartography function as tools to mold and influence human perceptions of the world. At its core, cartographic reason regards questions of representation and the cultural significances embedded within maps. It embodies a cognitive approach entwined with the rhetorical aspects of cartography, allowing those in positions of influence to delineate and dictate lives.
Moreover, cartographic reason serves as a lens through which the world can be understood, by integrating considerations of structure and function, objectivity and subjectivity. This integrative approach illuminates this understanding of the world. The significance of the concept lies in its capacity to unravel the ways in which maps and cartography have been wielded to shape our collective perceptions of the world, shedding light on the power dynamics embedded in this process. The three cited authors present nuanced perspectives on cartographic reason. Cosgrove centers on how geographical images can shape the imaginative positioning of the represented subject. Olsson provides a cognitive exploration of the influential power inherent in maps. Meanwhile, Farinelli emphasizes how cultural perspectives shape maps, subsequently influencing perception and power dynamics. Farinelli also asserts that we are currently experiencing a crisis in cartographic reason, driven by the fragmentation of modernist reasoning due to networked epistemologies.
In a related vein, Wilmott (2020) contends that contemporary digital mobile mapping practices can be viewed as expanded and transformative successors to the rationalist, universalist, and scientific impulses characterizing cartographic reason since the Enlightenment. However, Wilmott adds that analyses of cartographic discourse must extend into an investigation of the role of Leibnizian binary systems, universal characteristics, and elasticity.
Wilmott's work builds upon Farinelli's conceptualization of cartographic reason, exploring how digital technologies have metamorphosed cartographic practices and the consequential impact on our comprehension of space and place. Other geographers engaging with the notion of cartographic reason are Marcus Doel (1999), John Pickles (2012) as well as Jeremy Crampton & Matthew Wilson (2015) and David Turnbull (2008).

flickering across the screen—a technology hailing from a civilization whose intricacies I had not previously conceived.

A pivotal moment occurred when an engineer from a prominent company based in Oxfordshire elucidated the workings of this remarkable perceptual device to me. Intrigued, I embarked on a deeper exploration of its mathematical foundations. I sought out diverse examples and began contemplating the implications of such technology, particularly when integrated into the context of the smart-city framework, with which I was already familiar.

Lidar, an acronym derived from "light detection and ranging," constitutes a technology grounded in the fundamental principles of laser-based light emission and reflection. Operating within Lidar systems, a laser source emits discrete pulses of light that propagate towards and interact with objects situated within a given environment. These emitted light pulses undergo reflection upon encountering said objects and are subsequently captured by the Lidar system's receiver apparatus. The crux of Lidar's operational efficacy revolves around the precise measurement of the time required for these light pulses to embark on their outbound journey, interact with objects, and then return to the receiver—an essential concept referred to as "time of flight" (TOF). This TOF data is subsequently subjected to sophisticated processing algorithms, culminating in the generation of a detailed distance map (see Figure 1 for an example), delineating the spatial relationships and positions of objects inhabiting the observed scene (Behroozpour et al., 2017; Dong and Chen, 2017; Liu et al., 2018; Myllylä et al.; 1998; Raj et al., 2020; Wandinger, 2005).

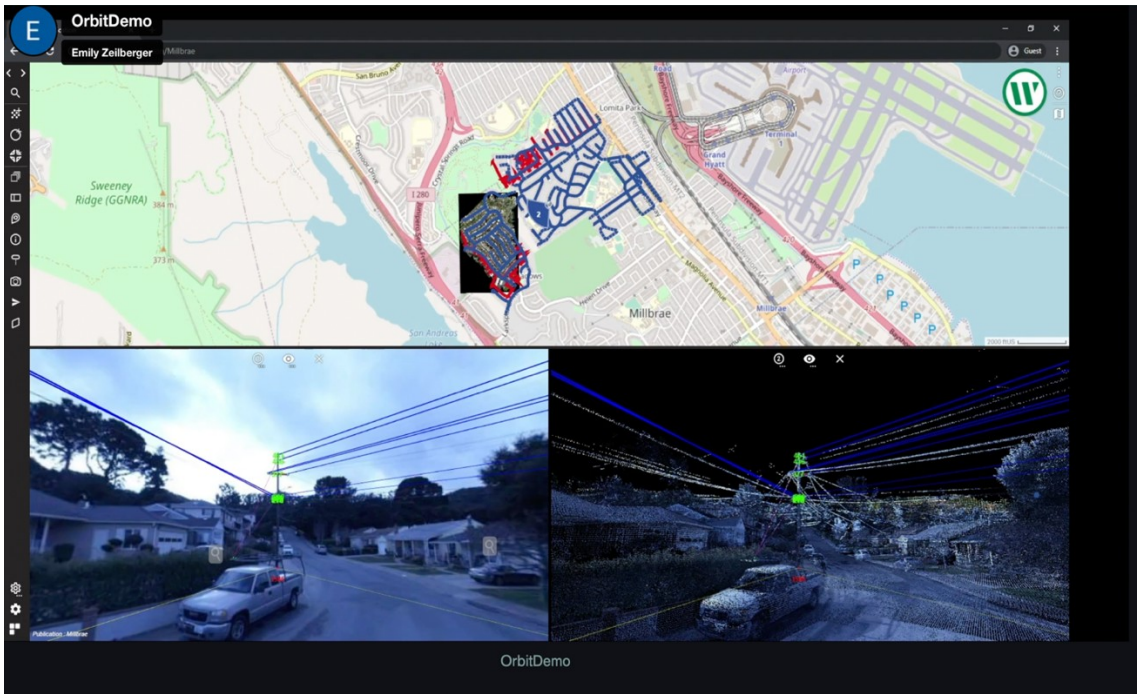


Figure 1 Screenshot taken by an Orbit GT demonstration video from https://storymaps.arcgis.com/stories/078d4d6f8f094e54b3f5c4dcf1905342 last accessed 25 April 2023. The demonstration of the brand Lidar viewer clearly shows the difference between different mapping forms.

The ascension of Lidar technology to a transformative status has been most conspicuously manifested within the dynamic sphere of start-up enterprises and established companies, actively immersed in the development of fully autonomous driverless vehicles (Wijeyasinghe, 2019). This technological evolution wants to fundamentally redefine the contours of the transportation landscape (Gargoum and El-Basyouny, 2017) and it has attracted significant attention and enthusiasm from a spectrum of stakeholders, including researchers (Hind, 2022, 2023; Sing and Saini, 2021), investors (Hawkins, 2021), and the broader public (Belkouri et al., 2021; Othman, 2021).

Lidar's exceptional capabilities, particularly its precision in environmental mapping and perception, have positioned it as an indispensable technology in the advancement of autonomous driving systems. Its utility extends across various areas of autonomous vehicle development, encompassing obstacle detection, navigation, and real-time

environmental mapping. Consequently, Lidar technology has ushered in a wave of innovation within the automotive industry, triggering extensive research initiatives, substantial investment, and entrepreneurial endeavors (Rogers et al., 2001; Steffensen et al., 2000).

The transformative role of Lidar technology in the domain of autonomous driving not only propels technological progress but also engenders crucial dialogues surrounding safety (Cunneen et al. 2020), ethics (Fleetwood, 2017), and the future of transportation (Bagloee et al., 2016; Taeihagh and Lim, 2019). Furthermore, it has fostered interdisciplinary collaborations, bridging fields such as engineering, computer science, data science, urban planning, and ethics. This underscores the profound significance and broad-reaching consequences of Lidar technology in today's technological landscape[2].

Between 2015 and 2020, there was a notable upsurge in the development of Lidar sensors for mobile terrestrial scanning (Rangwala, 2023), a trend that gained constant momentum following the second DARPA Challenge in 2007. During this event, a vehicle equipped with a rotating Lidar sensor emerged victorious, solidifying its status as a groundbreaking engineering innovation within the realm of research and development (Behringer et al., 2004).

Lidar technology swiftly assumed a prominent role (Hind, 2021), seemingly offering solutions to the multifaceted challenges associated with achieving fully autonomous driverless vehicles (Pulikkaseril and Lam, 2019). Nevertheless, the journey toward seamlessly integrating Lidar sensors into vehicles, harmonizing them with decision-

[2] It's not within the scope of this thesis, but is should be highlighted how Lidar technology has deeply impacted archeological research. See Sundell (2022) for latest trends in cyber archeology, and the literature around ethics and colonization of lidar data (Chase et al., 2020; Cohen et al. 2020; Fernandez-Diaz et al., 2018).

making software and design, encountered setbacks and fluctuations in enthusiasm (McManamon, 2019). These challenges underscore the vulnerability of an ecosystem lacking a robust and sustainable business development strategy (Rangwala, 2021b).

Despite these obstacles, manufacturers, investors, and proponents continue to extol Lidar imaging's virtues through both rhetoric and visual representations. Lidar is hailed as a technology endowed with superhuman visual acuity, poised to revolutionize not only drivers' behavior (Hind, 2021) but also the configuration of spaces amenable to automation (Duarte and Ratti, 2018). The development of autonomous vehicles hinges on the ability to capture extensive spatial data sets, with Lidar sensors assuming a pivotal role in data extraction and three-dimensional modeling. This transformation sets the stage for a shift from the Internet of Things, to the Autonomy of Things (Rangwala, 2021a), significantly impacting the conceptualization of smart-cities (Cugurullo, 2020).

As the production of Lidar sensors progresses toward full digitalization, mechanical components are gradually supplanted by electronically integrated transistors (Watts et al.; 2023). Smaller, fully scalable Lidar chips are making their way into smartphones, alongside conventional cameras (Costantino et al., 2022). Speculation abounds concerning the consequences of this technology's widespread adoption, underscoring the pressing need for a critical examination of the aesthetic and political implications intrinsic to Lidar imaging, as it becomes mobile and diffused among a wider public.

This project responds to the call for the development of new philosophies of digital mapping, as articulated by Perkins (2003). It seeks to interpret Lidar imaging as an outcome of advancements in driverless cars, which are considered emerging media (Huhtamo, 2020; Sheller, 2007) that generate spatial information within the context of

urban digitalization. Lidar technology represents a significant departure from conventional sensing and spatial control methods, necessitating a nuanced exploration of the distinct power dynamics and knowledge paradigms it introduces. This comprehensive understanding is crucial for assessing both the associated risks and potentials.

My interest in technologies applied to urban environments initially emerged while studying the connections between different architectural forms and processes of zoning and control, a project inspired primarily by Weizman's *Forensic Architecture* collaborative results (2017). During my academic pursuits, I began to consider the perspective offered by drones and the types of mappings they could produce as a reflection of a specific way of perceiving the environment and managing space (Belloni, 2018). I was intrigued by the digital augmented city and aimed to analyze the image of the city conceived by viewing it through a multitude of sensors scattered throughout the urban landscape (Gordon, 2010).

However, my encounter with Lidar imaging revealed a particularly challenging entry point for analyzing spatial matters and their digital representations. Firstly, Lidar technology operates in three dimensions and involves multiple layers of coding and data processing. Secondly, despite its status as a documented source for digital mapping in manuals (Kraak and Ormeling, 2010; Longley et al., 2015; Wilson, 2014), Lidar is more closely aligned with engineering, rather than with fields like geography or critical cartography.

My goal was to uncover the power dynamics and syntax of perception inscribed within Lidar imaging, without succumbing to melancholia (Rancière, 2008:43) and other emotional undertows, nor simply echoing mainstream discourse. This endeavor was

driven by my interest in how digital technologies are practically integrated into everyday life. In the case of fully autonomous driverless vehicles, which is the claimed and publicized end-goal of companies investing in Lidar, this integration would result in significant interventions in how life circulates within our cities (Arena and Ticali, 2018; Arena et al., 2020), encompassing the movement of people, goods, ideas, events, and encounters, among other things.

The city envisioned by proponents of this autonomous future is depicted as pristine, devoid of sharp edges, composed of iron and glass, and predominantly white. It is a city characterized by a lack of friction, with a smooth flow of vehicles that are aesthetically pleasing as well as ordered (Lorinc, 2022; Picon, 2018). This vision is often presented through narratives of artificial intelligence as a universal solution, capable of addressing all metropolitan challenges. However, it is crucial to recognize that digital technologies are not a universal panacea (Batty, 2018; Coeckelbergh, 2022; Cugurullo, 2021; Kassens-Noor and Hintze, 2021; Kitchin, 2014; Palmini and Cugurullo, 2023; Willis and Aurigi, 2017), but rather a set of functions designed to solve specific tasks based on available data.

The implementation of autonomy, as envisioned by commercial companies heavily invested in Lidar technology, implies a substantial infrastructural intervention. This intervention entails various commercial, ethical, and social considerations that must be harmonized into a unified framework. Cities are replete with diverse events, and while each event can be expressed as a function within a manifold -- the space of machine learning (Cayton, 2008; Fefferman et al., 2016; Gorban and Tyukin, 2018) -- there is no empirical evidence to support the idea that every event can be translated into a function, thus seamlessly integrated on the plane of the manifold.

Indeed, the quest for scholars who share this approach to Lidar technology reveals the challenges of finding a balanced perspective. On one hand, some researchers are said to exaggerate in the emphasis of the military origin of certain visualization technologies, without fully appreciating the marvel of the technology itself (Kellner, 1999; Mcquire, 2019). On the other hand, authors may focus primarily on the description of these devices, inadvertently reifying categories designed for such descriptions, thus neglecting to engage in critical examinations of the material and epistemic effects associated with such technologies (Hind, 2022; 2023).

Another group of researchers takes a different path, concentrating on the relationships between images and other images, or between images and their creators or consumers. While this approach seeks to avoid the pitfalls of representationalism (Anderson, 2019), it sometimes leans toward a form of unified vitalism that creates metaphysical duplicates of the entities being studied (Bissell and Fuller, 2017; McCosker and Wilken, 2020). This can lead to a solutionism that does not address core issues represented by AI urbanism (Cugurullo et al., 2023). In contrast, my intention is to approach the formal nature of the cartographic problems raised by Lidar imaging[3], to describe the *imaginary* that conditions it and is in turn reinforced by it, then to provide an understanding of the pipeline from data to visual output and describe how materials and processes condition human perception.

[3] In this context and throughout this thesis, when I employ terms related to the "formal" domain, I am specifically addressing the structural and procedural aspects inherent in cartographic challenges associated with Lidar sensing and its visual representations. This encompasses an understanding of the technical frameworks, methodologies, and principles governing the generation, processing, and interpretation of Lidar data. These aspects will be explored in detail in the final two empirical chapters of this thesis. It is important to emphasize that this focus on formality, which directs attention to the effects produced by a given structure, is complemented by a theoretical dimension that will be fully developed in the subsequent chapter. It should be noted here, however, that this thesis primarily examines the effects logically derived from established structures, which facilitate certain actions, in order to illustrate the potential *horizons of possibility,* mentioned in the inaugurating paragraph of this Introduction, afforded by such tools and associated practices. In essence, this thesis seeks to explore the boundaries of what can be articulated, conceptualized, and achieved through the dissemination and normalization of specific devices and associated visual outputs.

My approach is therefore rooted in a desire to critically examine the technology itself, appreciating its wonder, while also acknowledging its complexities and potential risks. By focusing on the formal aspects, I aim to provide a nuanced understanding of Lidar imaging that avoids both overly critical and overly enthusiastic perspectives. This approach is essential for fostering a well-rounded and informed discourse surrounding the technology and its implications.

1.2 Flotsam/jetsam/lagan/derelict

To circumvent the philosophical quandaries inherent in this endeavor, I devised a strategic approach that allows me to probe for the main scope of this thesis: how certain technologies perpetuate inherited horizons of possibilities in the spatial management they propose through certain images. This approach involves navigating perilous intellectual waters, tethering myself to found objects – flotsam – encountered along the way, and claiming them as components of my journey, all while refraining from becoming overly attached to the potential philosophical traps of an entire system of thought (Bederman, 1998; Dromgoole, 1999; Keith, 2016).

In essence, my strategy hinges on avoiding unwavering allegiance to any single philosophical framework. Instead, I opt for a contingent utilization of concepts, employing them as they align with the specific objectives of my project. This flexible approach shields me from the trappings of dogmatic authority and the allure of consensus-driven narratives.

My initial point of embarkation in this scholarly voyage involved an examination of the layers of digital labor (Bucher and Fieseler, 2017; Vertesi, 2012; 2015) that often remain

concealed beneath the glossy veneer of data visualizations. I sought to unveil the social and material efforts that underpin the creation of the polished visual outputs commonly showcased at exhibitions, conferences, in publications, and on websites (Wilson, 2012).

A paramount conceptual tool guiding me through this intellectual adventure was the notion of "epistemic cultures" (Cetina, 1999). This concept denotes the emergent of a collective way of connecting theory and the empirical from a defined group of experts, who not only share physical spaces but also engage in communal practices, conceptualizations, assumptions, and common objectives. It provides a framework for elucidating the collaborative processes through which these communities collectively shape knowledge production and the crafting of visual representations.

However, this initial foray into understanding the elusive nature of Lidar imaging, and its transformative impact on power dynamics within mapping, encountered significant challenges when attempting to engage with the engineering community. I observed a certain reverence for specific renowned figures and a prevailing narrative that upholds the myth of the self-made individual, capable of translating technological visions into reality within the confines of their own garage before catapulting their inventions into the realm of high-tech finance. Notably, I use male pronouns deliberately here, because I found that this community is heavily gendered. It tends to depict a mythical trajectory, from rags to riches, that is predominantly reserved for males. My experience as a woman attempting to navigate this community was met with skepticism and reluctance to engage with my inquiries.

While I encountered challenges in obtaining interviews, I engaged in numerous e-mail exchanges and cold calls in my quest for contacts, particularly within UK and Europe-based companies. These interactions ranged from conversations with undergraduate

students recruited by prominent firms to discussions with employees, division managers, established faculty, veterans in the field of photonics, and others. The responses I received were diverse and, to my surprise, often emotionally charged.

Upon reflection, I recognize that my questions posed a significant challenge for engineers. I sought to unearth the underlying practices and personal significance, persistently circumnavigating the well-established explanations typically reserved for outsiders. This process seemed to disturb the surface, aiming for the core of their professional identities and meanings.

The methodological challenge presented by industrial secrecy and the inherent difficulty of reflecting upon meta-semiotic questions necessitated finding innovative approaches to circumvent the limitation of words that cannot adequately describe themselves, a predicament akin to Turing's endeavor to outflank Gödel's paradox[4]. Despite the challenges posed by articulating this subject verbally, it remains crucial to address it, in spite of the limitations of our language and the individuals who create and circulate it. The fact that our words often prove inadequate to discuss the subject matter at hand highlights the absence of a comprehensive digital public sphere (Cohen et al., 2021) and reflects the prevailing perspective within mainstream engineering epistemology, where understanding how and why something works is often secondary to its functional utility (Galison, 2004). This simplistic view of technoscience, which encompasses scientific practice and the tools it employs to interpret the world, not only fails to provide enlightening explanations to the public but also carries inherent risks.

[4] I'm referring here to the paradoxes of the hermeneutic circle, especially how it has been formulated by Gadamer (1990). As complete understanding of a text can never be achieved, I associate these problems to Godel's second incompleteness theory, which states that a system cannot prove its own consistency (Godel, 2020; Carl, 2022).

Cities have undergone profound transformations due to data governance processes, and geographers have diligently explored the potentials and pitfalls arising from the adoption of new data collection and sorting technologies (Graham M. et al., 2022; Chen et al., 2018; Thrift, 2014). The involvement of private entities in policymaking has been metaphorically likened to a *Trojan Horse* by several scholars—an ostensibly innocuous virus silently spreading and undermining urban public values (Bharosa, 2022). In describing the novel dynamics of technologically mediated power, scholars have encountered the concept of black-boxing in algorithmic technology (Crawford 2021; Cubitt, 2014; Pasquale, 2015) and the challenges posed by industrial secrecy (Galison and May, 2014), which render digital devices enigmatic objects, resistant to critical scrutiny.

However, scholars have raised concerns regarding questions of agency (Rose, 2017), new biopolitical processes (Braun, 2011; Kraftl, 2014), and the proliferation of surveillance practices (Melgaço and van Brakel, 2021), which result in the fragmentation of urban spaces and the creation of uncertain experimental arenas (Dowling and McGuirk, 2020; Mattern, 2020; Marres, 2020). Demanding data transparency alone does not offer a definitive solution to the complex issue of technological opacity (Levy and Johns, 2016). Transparency is insufficient when the technology is deeply ingrained in a complex system of imaginations, claims, and practices that perpetuate themselves unquestioned. Moving beyond an ethical and political plea for transparency necessitates a focused examination of the horizon of possibility opened and sustained by tools that inherently possess significant epistemic power.

This perspective does not negate the need for updated policies, but aims to complement practical approaches with theoretical insights into the inner workings of digital objects, which are often overlooked in terms of their materiality and the consequences they

generate. Technological opacity has become automated within standardized procedures for data collection, sorting, and visualization, as observed during the evidence gathering phase of this research. In the ongoing debate surrounding the normative influence of visual technologies — whether it is intentionally hidden and naturalized for malicious purposes or occurs unconsciously — I argue that secrecy is increasingly being ingrained automatically. What was once a trade secret has now become an automatic response, informed by institutions and the normative sets of actions they perpetuate. An ostensibly benign program promising to automate mundane tasks and improve overall quality of life conceals the ghost of its origin. The aim of this inquiry is not to unilaterally attribute malevolent intentions or promote Luddite sentiments. Rather, it is essential to comprehend the origins and inner workings of these technologies. This thesis aims, through an empirical study, to unveil what has remained shrouded in darkness, to demystify the black-box.

In the pursuit of comprehending how Lidar technology both influences and is shaped by normative conceptions of space, this thesis embarks on an exploration with interconnected objectives.

The primary aim is to probe the discourse surrounding Lidar imaging, mapping, decoding, and deciphering the narratives that envelop it. This entails identifying the underlying codes and signifiers within the discourse, shedding light on the role Lidar plays in constructing specific spatial and temporal paradigms.

Simultaneously, the research plunges in the relationship between Lidar's data collection processes and the subsequent creation of visual representations. This analysis dissects

how data is gathered, processed, and transformed into visual forms, unveiling the mechanisms through which Lidar generates and disseminates spatial knowledge.

Moreover, the study is dedicated to elucidating the spatial and temporal dimensions that emerge as a consequence of deploying Lidar imaging. This involves an exploration of how Lidar technology shapes our perceptions of space and time, painting a vivid picture of the profound implications tied to Lidar's role in the spatial management of metropolitan areas.

In the process of this inquiry, a critical lens is applied to the mainstream discourse surrounding Lidar technology. The examination of this discourse aims to reveal the interplay of power and knowledge deeply embedded within Lidar's capacity to manage space. Additionally, it will facilitate the recognition and description of enduring Cartesian residual conceptions, as outlined by Ihde (2012), which hold substantial consequences for our understanding of the relationships between humans and technology.

Ultimately, the overarching goal is to foster a deeper understanding of the profound impact that Lidar imaging wields over our conceptions of space, time and more. This research seeks to unveil the dynamics of power and knowledge at play within this transformative technology. The first two empirical chapters are thus hinging upon the idea of the *imaginary*, the last two empirical chapters deal with the *digital materiality* of Lidar.

While Chapter Two recounts the theoretical underpinnings gathered throughout this research journey, Chapter Three details the operationalization of the research questions briefly outlined earlier. The chapter offers an account of the obstacles encountered during the data collection process, accompanied by the strategies employed to facilitate the

analysis. These solutions were instrumental in generating provisional answers to the primary inquiries addressed in this study.

Chapter Four is a central analytical core of this study, grounded in an online survey of Lidar production companies, specializing in autonomous vehicles. These companies utilize visual marketing strategies to establish themselves as leaders, fostering investor interest and collaborations. The chapter focuses on the visual representations of Lidar technology, often referred to as 3D or HD maps, which deviate from traditional cartography in both appearance and function. These images play a crucial role in shaping brand identities and marketing strategies, owing to their unique visual and functional attributes.

This chapter serves a dual purpose: to archive Lidar imaging from commercial websites and to analyze these images to understand the prominence of their online presence. These visual depictions are examined through the lens of persuasive geographic imaging techniques, highlighting Lidar's significance in branding and its broader implications. The chapter also identifies historical instances of promotional mapping, emphasizing the potential racial consequences of infrastructural projects.

Chapter Five extends the analysis by examining the commercial imaginaries of Lidar companies and their influence on perception, usage, and purposes of Lidar imaging. The chapter explores the discourse surrounding Lidar technology, emphasizing its role in shaping future cities while explicitly prioritizing a specific kind of safety. It also identifies the interconnectedness of Lidar's historical positioning in cartography, power structures, and knowledge paradigms.

Chapter Six focuses on the moving map, positioning it as the central theme of the discussion. It draws inspiration from Crary's exploration of optical toys (1992) as a precursor to the analysis and emphasizes the materials that contribute to Lidar imaging's cybernetic allure. The chapter begins with a historical overview, tracing the evolution of animated maps from World War II to the Aspen moving map.

The chapter then transitions to Lidar videos, applying concepts from film theory, to examine spatial significance, spectatorship dynamics, color palettes, point of view, and rhythmic elements. Lidar imaging raises intricate notions of subjectification and objectification, often with elements of magical thought and anthropomorphism. It shifts the focus from physical objects to intercepted surfaces through data visualization and software-driven segmentation, creating hieratic[5] surface models that extend beyond Euclidean geometry and human perspective, while reinforcing it.

The application of film theory sheds light on Lidar technology's complexities, linking it to cinema and defense research. This interdisciplinary approach is supported by the sensor's material evolution, offering profound insights into its mechanics and implications.

In the subsequent chapter, I recount the historical trajectory of Lidar technology, from its inception to its contemporary forms. This exploration investigates the evolving ideas, materials, convergences, schisms, and iterative experiments that have shaped the development of Lidar. Intriguing connections between Lidar and seemingly unrelated technologies, like searchlights, cinema, spectacle, and telecommunications, are

[5] In this context and throughout this thesis, I have chosen to employ the term "hieratic" to characterize digital visuals, particularly those derived from Lidar imaging. The choice of this term is deliberate and stems from its ability to encapsulate the complex, as we have seen in passing and will see in detail in next chapters, nature of these visuals. "Hieratic" conjures imagery associated with the mysterious and esoteric, suggesting an exteriority that requires a certain level of textual dexterity to fully comprehend. Moreover, the term "hieratic" also alludes to the irrational and slightly theological aspects that permeate my analysis of these visuals and are especially explored in the notes. By invoking notions of hierarchy and ritualistic symbolism, this lexical choice underscores the depth and significance of these visuals beyond their surface appearance. Also, on the “priesthood” of programmers cfr. Chun (2011:44); Crawford (2021).

uncovered. Additionally, I describe the digital materiality of Lidar, aiming to unravel the foundational and phenomenological aspects of the Lidar experience beyond its commercial discourse.

Chapter Eight shifts its focus to the temporal dimension of Lidar sensing within the context of Surveillance Studies. It explores the intersection of temporal aspects and surveillance, particularly considering Lidar's role in the development of driverless cars, and beyond. The chapter explores the transformation of mobility and its consequences for security, privacy, and racial dynamics. Additionally, it introduces the concept of *data flow*, emphasizing Lidar's contribution to reshaping urban landscapes and the relationships between humans, technology, and the world.

Chapter Nine offers a summary of the conclusions drawn from the empirical chapters' exploration and sets the stage for a counter-conceptualization of Lidar imaging as a possible generative emblem of technoscience.

In summary, this study approaches Lidar imaging from various angles, bridging disciplines such as Cartography, Human-Machine Interface Studies, Surveillance Studies, and Critical Data Studies. On the background, broader themes connected with the smart-city framework still are animated, sustained by theoretical wars among novel ontologies. The research highlights Lidar's distinctive visual and functional characteristics, its impact on branding and urban development, and its potential implications in surveillance and biopolitics. The study wants to provide a comprehensive, although provisional, understanding of Lidar imaging, and the array of challenges it poses in the interplay between urban data, their visualizations, and their deployment.

Chapter 2

Critical Reflections:

Lidar Imaging in the Nexus of Digital-Visual Human Geography, Surveillance, and Data Studies

2.1 Introduction

The city serves as the convergence point where materiality and imagination collide, creating a visual perceptual explosion (Ravesi, 2010). Following decades of technocratic visions shaping urban landscapes (Batty, 2013; Lynch, 1960; Ho, 2018), a variety of technologies have become embedded in the toolkit of city-builders (Lorinc, 2022), with Lidar standing out among them (Garnett and Adams, 2018), thus warranting a critical examination. Lidar is employed by companies promoting their mapping capabilities for the envisioned fully autonomous driverless car in urban sites, an objective still distant due to technical and political constraints (Martínez-Díaz and Soriguera, 2018; Padmaja et al., 2023). Nevertheless, Lidar imaging emerges, both online, on companies' websites, and at conferences and fairs, as the product of a fully established and reliable remote sensing tool that can be deployed for a variety of purposes. Such claims demand understanding and analysis, to unravel the patterns of power-knowledge that will be inscribed within the imagined city of the future, as the sensor becomes widely deployed toward the objective of autonomy.

Within the digitization of the urban landscape, the advent of experiments with driverless cars has transformed the street into a space to be automated (Cugurullo, 2020; Hopkins and Schwanen, 2018; Wang, 2021), thereby subject to data mining for surveying purposes. Unmanned vehicles have faced criticism for the myriad challenges they pose in the realms of mobility (Agriesti et al., 2020; Nikita et al., 2019; Jones et al., 2023; Smolnicki et al., 2016;), policy (Cabrales et al., 2019; Hopkins and Schwanen, 2018b; Karlin-Resnick et al., 2018; Metz, 2018), privacy (Fagnant and Kockelman, 2015; Kaur and Rampersad, 2018), security (Arena et. al, 2018; McBride, 2016; Some et al., 2019), and surveillance (Alvarez Leon, 2019), challenging the seemingly seamless narrative that

supports them with unquestionable confidence. However, I posit that Lidar imaging, employed as a form of *persuasive cartography* (Tyner 1982; 2014; 2020) exhibited on companies' websites, can be further dissected to unravel the implicit normative power embedded within the data visualization it produces and presents. To undertake this analysis, I adopt Dodge's (2018) concept of geovisualities, signifying augmented mapping methods characterized by both a vertical perspective (Elden 2013; Graham S. and Hewitt 2013) and new terrestrial forms of mobile mapping (Wilmott, 2017; 2020). While these innovative mapping approaches may unlock fresh interactions with geographical knowledge (Edler, 2020; Haklay, 2017; Quinn and MacEachren, 2018; Roth et al., 2017; Salovaara, 2016) this thesis primarily seeks to unearth the power dynamics ingrained within lidar geovisualities and the corresponding imaginaries they uphold (Beer, 2018). In other words, the HD maps outputted by Lidar sensors are framed as geovisualities, as a starting point for cartographic analysis, to then unearth processes and meanings further.

To further analyze the cartographic significance of Lidar imaging, in alignment with the framework articulated by David Beer in his influential work, *The Data Gaze* (2018) -- which scrutinizes the social and operational implications of data analytics and data capitalism -- the first key insight to consider is represented by the non-neutrality of extracted and examined data, in order to predict human behavior. Cultural and visual scholars have been looking at the elements that compose systems that organize vision, considering how such systems conditions how images and their meanings are perceived, understood, and sometimes challenged, shaping individual and collective experiences, ideologies and modes of knowledge production (Feldman, 1997; Foster, 1988; Krauss, 1988; 1993; Metz, 1977). For example, different visual media like art, photography, film, television and advertising can play a crucial role in organizing and disseminating such

invisible structures that have larger cultural effects. This is especially true when looking at advancements in technology. Concurrently, *data analytics,* as it is proposed by David Beer, presents a process of scrutinizing datasets to derive operational insights. Therefore, the utilization of *data analytics* can be perceived as an instantiation of an *algorithmic* instance of the kind of larger systemic structures mentioned before. This involves employing algorithms to analyze and interpret data, mainly spatial within this project, taking concrete form in a set of visual outputs, epitomizing a transformative approach to perception.

Data analytics becomes the method of choice for exercising power over visual data, influencing its interpretation and understanding. In other words, data analytics emerges as a mechanism for shaping visuality by leveraging data to draw conclusions from visual datasets. This process echoes the impact of the studies conducted by such cultural and visual scholars, on how humans perceive and comprehend the world. Integrating this set of views with the media archaeology presented by Crary in his seminal book *Techniques of the Obeserver* (1992), something interesting about the dialectic between imaginary, visuality and visual perception can be said[6].

Crary begins by acknowledging the radical transformation of the conception of both the subject and the observed world due to the diffusion of new forms of computer-mediated vision (1992:1).

However, Crary's historical account of the co-evolution of vision and perception, encompassing various optical toys alongside renewed scientific interest in the physiology and psychology of human vision, is grounded in an effort to bring clarity to the ambiguities resulting from a history marked by ruptures in the evolution of vision.

[6] Given the empirical constraints of this thesis, conclusions will be limited to what empirically emerges from collected data. However, it should be noted that the data analytics of Beer, regarding a game of gazing, is connected to the concept of "scopic regime" (Jay, 1988) and its discourse.

One primary concern arises from how art history traditionally places avant-garde experimentation within modernism as a rupture from the subjectivity defining vision during the Renaissance. Crary contends that both these divisions are idealized and illustrate the depth of the power of abstraction. He argues that it is essential to view both phenomena, and their theoretical renderings, "as overlapping components of a single social surface" (1992:5), dating back to the advent of optical toys like stereoscopes and phenakistiscopes, widely diffused in the early 19th century. These mass visual culture props are described by Crary as "inextricably dependent on a new arrangement about the body and the constitutive relation of that knowledge to social power" (1992:17).

Apart from their frequent use for the dissemination of pornography, Crary considers the remaking of experience through the reworking of vision and visual perception from a formal perspective, which means, focusing on the structural elements that compose the system that organizes vision. The ultimate objective was to render the individual quantifiable and manageable, transforming "human vision into something measurable and thus exchangeable" (1992:17).[7]

David Beer's study (2018) actively bridges the gaps in describing the specific gaze vehiculated by the logic of *data analytics*, but in doing so he programmatically focuses on textual prosodies, to retrace the building of a social imaginary (2018:67).

In methodologically extending Beer's premises, so as to focus primarily on the visual aspects of the data imaginary he has individuated, this thesis aims to contribute to three

[7] Studies that highlight modification in perception advanced by mode of transportation are Terranova (2014) and Schivelbusch (1986).

primary geospatial literatures. Firstly, it aligns with a critical comprehension of how augmented maps are reshaping the landscape of digital cartography. Secondly, it seeks to define how specific technical visions might significantly impact environmental management, introducing novel patterns of knowledge-power, masked by their seemingly neutral appearance. Finally, it explores the enmeshment of humans within the materiality of digital systems, particularly concerning issues of surveillance within a broader, technically mediated, algorithmic imaginary (Beer, 2009; 2017).

This chapter is divided into two main parts. The first part presents an explorative literature that seeks to reconstruct how data are mined, elaborated and transformed into visual outputs, along a pipeline that travels from the visible to the invisible. From phenomenological world to the appearance of Lidar mapping on the screen, that black-boxes calculation processes involved in the pulverization of the material in cyberspace. The initial segment thus explores Critical Data Studies, offering insights into the dynamics surrounding data interpretation, ethical considerations, and broader implications. Subsequently, the focus shifts to Surveillance Studies, unraveling how monitoring, governance, and the ethical discourse are connected to watching and being watched. A pivotal section follows, examining the role of images and visual data in shaping perceptions of space and place.

The second part of the chapter introduces the preferred theoretical framework guiding this study: post-phenomenology of technology. This framework provides a lens for understanding the dialectic between technology, human experience, and the built environment.

It is essential to recognize that the subject matter at hand is characterized by fuzzy boundaries, mirroring the complex and evolving nature of technology and its impact on human geography, and culture more broadly, as provisionally indicated in the Introduction. The chosen literatures reflect the academic background and positionality of the researcher, aligning with a focus on the internal coherence of this specific project and how it has been developed. However, these limitations, rather than hindrances, can be considered as catalysts for the continual evolution and refinement of the research effort.

2.2 Critical Data Studies and the Evolving Algorithmic Landscape

Over the past decade, the heightened interest in "Big Data" and its diverse applications, propelled by economic and political motives, has become a focal point for scholars and the general public. Lev Manovich's groundbreaking work, *The Language of New Media* (2002), marked the inception of exploring data-capturing objects for tailoring personalized user experiences within cinematic aesthetics. However, events like the 2013 Edward Snowden case, unveiling mass surveillance, and the notorious Cambridge Analytica scandal in 2018, have intensified scrutiny. Works such as Cathy O'Neill's *Weapons of Math Destruction* (2017) have brought into focus seemingly neutral algorithms that perpetuate biases, impacting lives in unpredictable ways.

The deluge of data, whether big or small, from various platforms, has its roots in a belief in the neutrality of quantitative methodologies. Jose Van Djick (2014) emphasizes the conceptual shift resulting from public trust, influencing modifications in surveillance practices. *Dataveillance* involves the continuous tracking of (meta)data for unspecified purposes, contrasting with traditional surveillance, focused on specific goals.

The call for critical reflection on Big Data came from Craig Dalton and Jim Thatcher in their pivotal paper "What Does a Critical Data Study Look Like, and Why Do We Care?"

(2014). They advocate for critical studies to question the naturalization of Big Data in society, urging geographers, especially, to explore the capabilities and limitations of numbers, emphasizing the significance of old quantitative small data and qualitative methodologies.

Editors Andrew Iliadis and Federica Russo (2016), in their exploration of Critical Data Studies in the journal "Big Data and Society," explore various perspectives questioning data. They argue that critical data studies are inherently political, aiming to comprehend the politics and discontents of data, while engaging with society at large through digital literacy or policy-making.

Levy and Johns (2016) address the weaponization of transparency in Big Data, asserting that open access to environmental data can serve as a *Trojan Horse* to normalize data mining and collection under the guise of ethical sharing. The opacity of algorithms and machine learning is tackled by Jenna Burrell (2016), who contends that confronting the mathematical optimization of machine learning is crucial. She highlights the need to scrutinize algorithms themselves, as many are intentionally hidden by companies, contributing to algorithmic opacity.

Adam Burke (2019) challenges the prevailing notion of algorithms in contemporary software, distinguishing between a technical definition in structured programming and the broader understanding as a software platform making impactful decisions based on an invisible mechanism. He explores how algorithms, as agents of transparency in structured programming, become layers of code that progressively fall into invisibility through reuse.

"Code/Space: Software and Everyday Life" (2011) by Martin Dodge and Rob Kitchin is a seminal text connecting Critical Data Studies with Software Studies. The book emanates from the necessity to understand the co-production of software and everyday spatialities, given that almost all activities connected to collective life are now mediated by

computational technologies. Opting to live logged off, the authors argue, is a choice that doesn't bring much difference, as both passivity and activity can be easily registered and made sense of. The book reframes data as *capta*. Data is a piece of information that can be harnessed about an entity, whereas capta is "what is selectively captured through measurement" (2011:4). The main scope of the book is to analyze the co-production of space and code in different and unavoidable areas of life: traveling, dwelling, consuming, where governance and empowerment meet in contradictory ways, highlighting the technicity of code/space and the ontogenic nature of its operations. The authors introduce the concept of transduction (Mackenzie, 2002, 2003; Simondon, 1989a, 1989b, 1992, 1995), emphasizing the evolutionary and open-ended aspects of code/space. The book also explores the disciplining of subjects through automated management, wherein software plays a central role. Wendy Hui Kyong Chun's *Programmed Visions: Software and Memory* (2011) further explores the relationship between software and code. Chun contends that software, as a key unifying factor in new media, is a powerful metaphor for the invisible yet impactful processes in various domains. She explores the materialization of information as a gendered history of labor, highlighting the neoliberal essence of software as a form of governmentality.

In Bucher's *If...Then: Algorithmic Power and Politics* (2018), algorithms are analyzed from a feminist Sociology of Technology perspective, considering their relational features. The algorithm is seen as a dynamic and performative force that structures conditions, creating value through prediction.

Critical Data Studies exhibit great asymmetries on the spectrum of what they might entail, despite the clear definition given by Iliadis and Russo, among others.

The intersection between Critical Data Studies and Surveillance Studies is evident, stemming from a shared interest in the relationship between digital technologies and social processes. Both fields scrutinize the material actors shaping new governance

regimes and the discursive constructions supporting them. Critical Data Studies, while exhibiting asymmetries, emphasize the politics of algorithms, drawing attention to the specter of monitoring and opticality, implicit in understanding the omnipresence of algorithms.

Critical Data Studies, in contrast to Surveillance Studies, implicitly reintroduce the specter of monitoring and opticality.

2.3 Surveillance Studies and the Dynamics of Gazing

Surveillance Studies, an interdisciplinary field at the confluence of the sociology of policing, criminology, and the sociology of technology, has undergone significant development, thanks to influential scholars such as Lyon (2007) and Marx (2015). This multidisciplinary nature prompts critical currents within each discipline, encouraging a reassessment of established concepts.

The material space where surveillance practices unfold among different actors serves as the primary entry point into this field. However, the seminal works of Lyon and Marx, though comprehensive, lack specificity regarding the locus of analysis. They act as attempts at systematization. Nevertheless, these works leave open questions about the specific contexts and evolving dynamics of surveillance practices.

Lyon and Marx initiate their analyses with a broad definition of surveillance, encompassing almost any act associated with observation. Surveillance, as they posit, becomes a defining trait of human societies throughout history. This expansive definition, capturing almost every act related to watching, compels the need to categorize acts of seeing into benign and malevolent surveillance. Marx, in particular, diverges from Lyon by emphasizing the neutrality of surveillance, challenging the prevailing notion that

associates it solely with malevolence. This departure underscores the ongoing discourse within Surveillance Studies regarding the ethical implications of surveillance practices. The broad conceptualization of surveillance, influenced by Michel Foucault's metaphorical use of the Panopticon (1975), prompts a critical engagement with his legacy. Foucault's Panopticon is not revered for its mechanized surveillance but as a symbol of the internalization of control. However, Marx endeavors to dissociate surveillance from an inherently malevolent perspective, arguing against the common association of surveillance with the total institution of the prison. This critical dialogue with Foucault's ideas opens avenues for exploring alternative frameworks for understanding the motivations and consequences of surveillance practices.

The discussion also touches upon the need for self-reflection in studying surveillance, echoing Browne's question regarding the adoption of the surveillant gaze (2015). This emphasizes the importance of acknowledging research positionality in analyzing surveillance practices. The tendency to classify everything, a logic inherent to surveillance, is critiqued for its potential to introduce bias and obscure nuanced realities. This self-reflective dimension becomes crucial in unpacking the nature of surveillance studies, recognizing the impact of the role of observer on the observed.

The unease stemming from new technologies, as described by Zuboff in *Surveillance Capitalism* (2019), further complicates the landscape. The commodification of behavioral surplus through data mining poses ethical concerns, reducing human experiences to quantifiable data for commercial and political ends. This reductionist approach, coupled with the computational turn, transforms looking into tracking, fueling concerns about the impact on individual privacy and autonomy. This discussion opens a rich terrain for

exploring the evolving nature of surveillance practices in the digital age and the ethical considerations that accompany these advancements.

Klauser (2016) and Andrzejewski (2008) contribute to an understanding of the relationship between data and image. Klauser's exploration of power dynamics through architecture, intertwined with the socio-technical assemblage, emphasizes the role of technologies in shaping social conditions. The concept of the mediator, borrowed from actor-network theory, becomes instrumental in mapping the making of the social. Andrzejewski's distinction between discipline and security, informed by Foucault, further enriches the discourse by exploring how surveillance practices intersect with broader issues of social order and control.

Nishiyama's analysis of crowd surveillance in Japan (2018) highlights the racial implications of seemingly neutral technologies. The racial profiling embedded in surveillance practices underscores the need for a critical examination of the intersectionality of surveillance. This intersectional lens becomes crucial in unraveling the complex interplay between race, technology, and surveillance practices.
Nishiyama notices how the analysis is relevant also because such politics of the crowd have been discussed in the UK too with the “Protecting Crowded Places” guidelines (2014) from the Home Office. NEC’s technology captures images of crowds in public spaces, then the algorithm splits the image into manageable squares to analyze the scene and determine if the flow of people is behaving “normally.” This enables the system to identify a possible threat, simply monitoring how the flow moves through a space.

Another important aspect is the aesthetic dialectic between data and image, as explored by Anderson in *Technologies of Vision: The War between Data and Images* (2017). The

author states that to understand such a turn, it's necessary to formulate a politics of data, as these objects shift definitions of place, intention through sensing, and knowing through processing. No data can make sense to humans if not "cleaned" beforehand, made available for human interpretation through data visualization. Here lies the problem: computation is inherently non-mimetic. Therefore, translation, a sort of aesthetic manifestation of data devised for human understanding, becomes crucial. Anderson proceeds with a list of artistic manifestations of the dialectic between data and image, recognizing that actual surveillant systems, even those based on biometrics, rely on a cross-matching that is integrated with a camera-based system. In the computational turn, looking is becoming tracking, and the tracked body is of interest as an instance of a species.

The problematic relationship between the *datification of life* and visibility as a site of multiple struggles for and against power is the main theme in D'Agostinho's paper "Chroma Key Dreams: Algorithmic Visibility, Fleshy Images and Scenes of Recognition" (2018). The author, thinking through works of artist Sondra Perry, wants to build a political ontology of the image that is able to connect the computational turn to the visibility of the body marked through flesh. Her main thesis, using conceptual tools like Browne's black luminosity (2012) and Weheliye's Habeas Viscus (2014), is that visibility, a contested arena per se, when taken in its declension of race, is always already guided by an algorithmic logic, even in its pre-digital manifestations. The algorithmic logic is predictive and pre-emptive, wants to shed light on everything, obtaining transparency. It is the antagonistic force of Edouard Glissant's opacity and demands complete intelligibility (1997).

D'Agostinho indicates in Butler's idea of recognizability, as the ethical framework that enables encounters between subjects, exactly the opacity of the body. D'Agostinho

indicates in pre-digital photo and film ontology instruments to read through the computational turn: her idea of an optical unconscious of big data (2019), an idea borrowed from Rosalind Krauss in her discussion of early video-art focused on the body of the artist (1977), calls for a deeper analysis of the specter of opticality that still haunts computation and, therefore, the subject. D'Agostinho also makes use of "speculative ethics", a methodology emerging among new materialist black feminism as a way to open up the foreclosure of the datafied world through new imaginaries of the future.

Surveillance Studies currently presents a highly diversified field of interest, as the act of watching and gathering information can be explored in numerous ways. A significant section of the discourse revolves around the relationship between crime and policing, but there is also exploration into crime and profiling, policing and democracy, privacy and publicity, and privacy and policymaking.

Authors consistently attempt to identify ways to resist this systematic and ever-proliferating apparatus of watching and deterrence. Dencik (2018) explains that most calls for counteraction in academic papers push back responsibility on the individual, evading the need for a true political proposal. Koskela (2012) illustrates how "the gaze without eyes" affects the emotional space – that is also a container of power relations. Especially if such gaze is less and less visual and more haptic, dynamic, and gestural.

Critical Data Studies and Surveillance Studies share common ground in their examination of the complex relationships between information, power, and social dynamics. Both fields are inherently interdisciplinary, drawing insights from sociology, technology studies, and related disciplines to analyze the nature of contemporary data practices.

Convergences between the two fields lie in their acknowledgment of the profound impact of data-driven technologies. Both Critical Data Studies and Surveillance Studies recognize that the collection, analysis, and use of data are central to contemporary modes influencing structures of power and control.

However, key differences arise in their primary foci and perspectives. While Surveillance Studies traditionally concentrates on the broader landscape of surveillance, encompassing social control mechanisms and the implications of observation, Critical Data Studies specifically scrutinizes the role of data, emphasizing issues related to data ownership, privacy, and the ethical implications of data-driven decision-making.

2.4 Human Geography and Geovisualities

Human geography, as a field of study, occupies a unique vantage point that can significantly contribute to addressing the gaps within both Critical Data Studies and Surveillance Studies. In attempting to understand the ripples brought about the digitalization of space (Ash et al., 2018; Elwood and Leszczynski, 2018; Leszczynski, 2015; Leszczynski and Crampton, 2016), Human Geography brings a nuanced understanding of the spatial dimensions of data practices, shedding light on how data is produced (Graham and Shelton, 2013; Kitchin, 2021; Rowe, 2021), consumed, and contested (Graham et al., 2013; Graham et al., 2022; Glasze et al., 2023) in different geographical contexts. It provides a lens through which to analyze the uneven distribution of data resources (Graham et al., 2015; Thatcher et al., 2016), the geopolitics of data (Zook and Blankenship, 2018; Zook and Graham, 2018), and the socio-spatial implications of data-driven technologies (Amoore, 2009; Amoore and Hall, 2010; Eubanks, 2018; Gilbert, 2010; Gray, 2009; Jefferson, 2017; 2018; 2019; Kelley, 2018). Simultaneously, when looking at the main problems at the core of Surveillance Studies,

Human Geography contributes by emphasizing the importance of space and place in shaping practices. It recognizes how surveillance is not only a product of technological advancements but also deeply rooted in the socio-spatial organization of communities (Mattern, 2017; 2018; Turnbull et al., 2023). By incorporating the geospatial perspective offered by human geography, gaps in the current discourse can be bridged, offering an understanding of the relationships between data, surveillance, and the geographical dimensions of power and control (Datta and Odendaal, 2019), also considered through a generative lens (Edlere and Kühne, 2022; Elwood, 2021; Leszczynski, 2019; Maalsen, 2023; Rose, 2017), in an increasingly interconnected world.

Currently, there exists a scarcity of literature specifically addressing Lidar imaging from a critical geospatial perspective. Hind's contributions (2022; 2023) stand as the sole critical examination of Lidar imaging within the field of geography. Hind (2022) focuses on an incident wherein the integrated system, comprising various sensors, segmentation software, and a human-in-the-loop, failed, resulting in a tragic outcome. Subsequent to this incident, Hind's later work on lidar (2023) reiterates key insights derived from his earlier papers.

My project aims to view lidar imaging as a distinct aspect in the digital cartographic evolution. This perspective organizes the conditions of possibilities for perception and action in ways (Rancière, 2008; Dikeç, 2015) that need to be charted.

Hind’s work falls within an establish tendency that highlights when algorithms deviate from their intended governance, resulting in outcomes that diverge from the algorithmic goals or the platform's expectations. These *algorithmic fissures* may arise due to various factors such as manipulation, resistance, and contestation. Ferrari and Graham (2021) articulate algorithmic fissures as moments when algorithms fail to produce hegemonic outcomes and do not entirely strip away agency from platform workers. Instead, these

moments serve as opportunities for contestation and resistance, allowing workers and other actors to influence algorithmic outcomes and the platforms they operate on. Algorithmic fissures carry significant social and political implications as they challenge the power dynamics inherent in platforms and the algorithms governing them. They also create avenues for new forms of solidarity and resistance among workers and other entities, shaping the outcomes of algorithms and the platforms they operate on.

Conversely, Frank Pasquale introduces the concept of algorithmic operational-manufactured-smoothness in his book *The Black Box Society* (2015), highlighting how algorithms can be designed to project a veneer of smooth and seamless operation, concealing the underlying processes and decisions shaping their outcomes. This manufactured smoothness, as Pasquale contends, is achieved through various techniques. One such technique involves operationalizing the algorithm, presenting it as a seamless and automated process to discourage users from questioning its outcomes or the decisions influencing them. Another aspect is the strategy of manufacturing consent, portraying the algorithm as a neutral and objective tool to induce user acceptance without probing the underlying assumptions or biases. Additionally, creating a sense of inevitability by framing the algorithm as an indispensable part of the technological landscape discourages scrutiny of its outcomes and the decisions guiding them.

These insights represent a critical step in comprehending the functioning of digital technologies, repurposing a tenet of the visibility and invisibility dialectic inherent in infrastructure studies (Graham S., 2010; Larkin, 2013; Parks and Starosielski, 2015; Plantin, 2018; Plantin and Punathambekar, 2019) as flagged in the Introduction of this chapter. While the spatial relationship between Critical Data Studies and Surveillance Studies, emphasizes the circulation of gazes through algorithmic space management

practices, this discussion explores the intersection of the visual and digital products of GIS tools from the perspective of Human Geography. This underscores the need to consider how these tools shape the visual and digital, offering understandings about their impact on perception, action, and the broader horizon of intelligibility.

Geovisualizations constitutes a set of tools and techniques employed for the analysis and visualization of geospatial data. Utilizing cartographic technologies, this field leverages modern microprocessors to dynamically render changes on a map in real-time. Intersecting with other forms of scientific imaging, geovisualizations contributes to these domains through a geospatial lens. A closely related field, geovisual analytics, involves analytical reasoning with spatial information, facilitated by interactive visual interfaces. The applications of geovisualization span various domains, including wildland fire fighting, archaeology, and public health.

The concept of geovisuality becomes a lens through which to investigate issues around the relationship between environment, technology and the users, discerning how data processes mediate these concerns and its intimate connection to the relationship between visual, spatial and operational qualities embedded in the data pipeline.

Martin Dodge (2014; 2018) defines geovisualities as the various ways in which geospatial data is visualized and represented, with a keen focus on unraveling the social and political implications entwined in these visualizations. He argues that well-crafted map displays possess a remarkable ability to not only capture attention but also convey meaning swiftly through an instant gestalt.

On another note, the article "Guest Editorial: Affective Geovisualizations" (Aitken and Craine, 2006) discusses the potency of maps and the inherent distortions they can introduce. The author underscores warnings from cartographers regarding issues such as colonialism and propaganda that may emerge from map representations. Subsequently, the article explores the transformation of data exploration from traditional "map metaphors" to contemporary "new forms of multisensory and multimedia communication". Visual information gathering is now complemented by additional sensory stimuli.

Nevertheless, the authors contend that the crucial dimensions of affect and absorption have not received sufficient exploration. The article concludes advocating for the development of novel methods and techniques to both collect and analyze data effectively.

In a similar vein, "The Emotional Life of Maps and Other Visual Geographies" (Craine and Aitken, 2011) focuses upon the emotional and affective dimensions inherent in maps and visual geographies. The central argument posits that maps extend beyond neutral representations of space; instead, they are imbued with emotions and affective qualities. Additionally, the article calls attention towards the role of maps in shaping our understanding of space and place, mediating this understanding through emotions and affective responses. It thus highlights the transformative potential of maps.

While Dodge focuses on the formal qualities of images, especially considering ways to foster interactivity and novel data explorations, the article takes a distinct perspective, concentrating on the effects generated by these representations.

Various perspectives on the representation of geographical data have been extensively explored by scholars such as Boucher (2015), Bridge (2013), and Crampton (2016), each

contributing significant insights towards the understanding of the deployment of geovisualities. Boucher (2015) offers an example about images from above are used to manage public acceptance of civilian drones.

Bridge's perspective (2013) provides a commentary on the utilization of 3D Technology in Territorial Studies. This paper asserts that 3D technology holds the transformative potential to revolutionize the exploration of territory, offering a more nuanced comprehension of the vertical dimension within power dynamics. The argument posits that 3D technology can be instrumental in scrutinizing the spatial distribution of power and resources within a given territory, unveiling how power relations are influenced by the vertical dimension of space.

Crampton's contributions (2016) present an exploration of the interplay between commercial drones and the algorithmic life. This paper contends that drones constitute a crucial component within a broader assemblage of technologies reshaping our perception and engagement with the world. The study probes diverse applications of drones in commercial contexts, encompassing mapping and surveillance, and investigates their integration into expansive systems of algorithmic governance. The paper concludes by urging a discerning scrutiny of the social and political ramifications entwined with drone technology and algorithmic life. Like Boucher and Bridge, Crampton highlights the importance of recognizing the social and political implications of geospatial representations. He echoes diffused calls to consider the power dynamics inherent in map production and usage, reinforcing the idea that these dynamics play a crucial role in shaping perceptions of space and place.

Lidar (Light Detection and Ranging) serves as an optical remote-sensing technique, utilizing laser light to intricately sample the Earth's surface, yielding highly accurate x, y, z measurements (Taylor, 2019). Particularly prevalent in airborne laser mapping

applications, Lidar emerges as a cost-effective alternative to conventional surveying methods like photogrammetry. It generates mass point cloud datasets that ArcGIS Pro can effectively manage, visualize, analyze, and share (Fernandez et al., 2007). As an active optical sensor, Lidar transmits laser beams towards the surface while following specific survey routes. The reflected laser signals are detected and analyzed by receivers within the Lidar sensor, enabling range distance calculations. Lidar captures laser returns from objects both on and above the ground surface, including vegetation, buildings, and bridges. Lidar data can seamlessly integrate into GIS as a LAS dataset, facilitating access to extensive Lidar and surface data. The versatility of Lidar data unfolds in various visual representations, including 2D or 3D points, triangulated surface models (TIN), and visualizations based on elevation, slope, aspect, or contour lines (Demantké et al., 2012). These data can further fuel numerous 3D analysis tools and undergo point classification edits (Yastikli and Cetin, 2016).

Lidar, a pivotal remote sensing tool in GIS, finds applications across diverse fields of research. In geosciences, Lidar facilitates surveys of quarry sites, mining areas, and geological features (Hodgetts, 2009). Its utility extends to environmental assessments by detecting air pollutants and surveying surrounding landscapes to evaluate project impacts. In forensics and law enforcement, Lidar proves invaluable for tasks like blood splatter analysis, speed limit enforcement, and the 3D recording of accidents and crime scenes (Bahirat and Prabhakaran, 2017). Agriculture benefits from Lidar through non-destructive remote sensing applications, encompassing soil management, surface roughness analysis, and erosion control (Rivera et al., 2023).

Mapping and surveying endeavors leverage Lidar's capacity to generate detailed three-dimensional point clouds, providing comprehensive coordinate information. This tool is integral in producing accurate vector data for architecture and engineering projects

(Brook et al., 2010). In transportation, Lidar contributes to expanding mass transit systems and optimizing rail stations. By scanning surrounding areas, it generates actionable metrics related to passenger flows, luggage belt optimization, seat occupancy, and more (Zhangyu et al., 2021).

Because Lidar outputs are the results of algorithmic processes representing spatial data, I frame Lidar imaging as a form of geovisuality, that is then deployed by manufacturers as a form of visual persuasion, and as such is circulated online.

The discourse on images within narratives concerning the deployment of new technologies in urban settings is rich and diverse in the visual-digital branch of Human Geography, with several notable authors contributing pivotal insights. Anderson (2019) foregrounds the role played by images in shaping public perceptions of new urban technologies, emphasizing the implications of these perceptions. Barry (2021) explores the use of images in such narratives, stressing their influence on public perceptions and underscoring the imperative to critically examine the supporting narratives for their extensive implications.

Bissel and Fuller (2017) argue for the material agency of images as potent "agents" in the making of the future of mobility, rather than representation of a political power. Bos (2021) in its recognition around VR, builds upon Bissel and Fuller indication around the material agency of the visual, to invite further reflections upon content and its socio-cultural effects. Jackman (2022) proposes an understanding of the imagined futures of a politics of the drone for civil use, through the agency of speculative designs. On the contrary, Frith (2013) argues for the powerful influence of location-based games, capable of influencing how humans perceive the space and their mobility.

Latham and McCormack (2009) assert the significance of images as devices for understanding the more than relation and processual power of the "things" that populate

the urban. Rose (2016) and Rose and Willis (2019) contribute by exploring the role of digital-visual agents in shaping public perceptions, also deploying natively digital methods (Leszczynski, 2019).

These authors underscore the importance of understanding the productive implications of images, as they work as agent of new technologies in urban contexts. They advocate for an examination of images, recognizing their capacity for creating worlds, with nuanced understanding regarding embodied declensions of perception and theoretical novel installments describing relationships among agents. These branch of visual studies within human geography is rooted in a conceptualization of materiality that prefers the performative side of the relation and the affective circulation between human and non-human agents (Rose and Tolia-Kelly, 2012).

While such studies offer many interesting points about agency and new agents among the networked society, in order to answer to the specific research questions of this project, I turn to a conceptualization of materiality borrowed from the post-phenomenology of technology[8]. The material agency of images, while functional to highlighting the relations among different agents, proves to be less adaptable to an engineering field shrouded in trade secret, that clearly inhibits the circulation of agency. Moreover, both the second research question – about the pipeline from data to image – and the third question – about the effects on perception – would remain vacant without an apprehension of the digital materiality of Lidar sensing, considered in its constitutional elements and how they work at a molecular level, within a history mainly made by humans in their relation to the world.

[8] It should be noted that New Materialism and actor-network theory still present many differences among the various authors, as the philosophy is in constant evolution. Same can be said for the materiality of post-phenomenology, which foresees different definitions and preferred focuses, as it will become apparent in the next part of the chapter. It's worth noting that in the history of philosophy are present uncountable instantiations of materialism, for example: Leucippus, Democritus, Epicurus, Lucretius, Gassendi, Hobbes, Descartes, Spinoza, Hegel and Marx, just to name a few. See Wolfe (2016).

2.5 Epistemic tools

The idea of the epistemic tool comes from understanding a mediating technology like a sensor or a digital interface as representational machine that is a product of process of design imbued with values, categorizations, normalizations and abstractions that, at the same time, offers a series of affordances and constraints to the user (Magnusson, 2009). I'm taking this concept from the musicology of digital instruments, strongly based in Human-Machine Interactions, in trying to define the semiotic behavior of digital artifacts as well as their effects on human knowledge.

The concept of epistemic tools is not intended to define exclusively digital technologies; it includes all tools that work as props for symbolic offloading in our cognitive processes. Good examples of symbolic but analogue machines are the abacus and the astrolabe (Magnusson, 2009:169)

The epistemic tool – an idea that comes from the work of Don Ihde – can be a properly digital, as well as an analogical instrument – as it could be argued that, in their logic, the abacus and the astrolabe are already digital in the diagram they propose and impose of reality (Turnbull, 2000). However, the main point of the epistemic tool is that it is the coagulation of an ideology and can show its states. Framing Lidar imaging as the result of a process of data through epistemic tools would contribute to the debate around the infrastructures of knowledge and how they still thrive upon a modern idea of the subject (Edwards, 2002), while further exploring the dialectic of visibility and invisibility that emerged in Critical Data Studies, but directing the focus of attention *inside* the epistemic tool. The process of making visible (or not) the world -- projecting it into a diagram, a

grid, a map or an augmented map like a geovisuality -- is already inside the epistemic tool, by virtue of its design.

Ihde's conceptualization of technological instruments started in 1979 with the book *Technics and Praxis*. In Ihde's philosophy, the central point is constituted by giving more attention to the practices that constitute science, rather than the theory that functions as a substrate or a result of science. The favorite example brought upon by the philosopher is how Plato and Democritus put forward what could be considered foundational theories of reality, since science is a modern creation in human history, but their ideas, although complex, didn't give raise to significant advancement in culture and society. Conversely, Eratosthenes, manipulating specific instruments, was capable of measuring the circumference of the Earth with a surprising degree of precision (1979:XX; 38). In *Post phenomenology and Technoscience* (2009) this description of the importance of the instrument is also remarkedly declined to demystify the eurocentrism of technoscience (2009: 26; 30-31) -- that kind of science that is, in Ihde's thought, brought forth and led upon its evolution through the centrality of the technological instrument. In the first book, instead, the description is more gathered towards establishing the foundational relationship that constitutes the mediation of experience between the subject and the world (1979:3-40). Through a confrontation with Husserl, Heidegger and Jonas (1979:103-151), the instrument is here defined as a sort of filter that can function as an amplification or a reduction of the world to be observed and then known (1979:10-13). Both these modalities open up a transformation of the subject and the world (1979:65), a new way to see the world and therefore the possibility to expand knowledge about it. However, amplification and reduction need to be critically made explicit, because amplification tends to bring forth distortions, especially when it comes to spatial relationships. Conversely, reduction tends to naturalize and make invisible the technical

filter, bringing forth confusions regarding the boundaries between the subject and the world instrumentally mediated. This attention to the world is specified in *Technology and the Lifeworld* (1990), and its heritage of classic phenomenology (1990:31-42) which tries to find ways to avoid practices of objectification in science (1990:116-126), as well as what the author calls elsewhere (2012) a "Cartesianism Redux", which signals a tendency to adopt surpassed dichotomies, in doing and criticizing science and technology.

A lack of understanding of how reductionism and objectification work, and thus can be avoided, risks of projecting inherited scientific visions even upon instruments and advancements in technoscience that can bring forth new possibilities for the organization of the world that hosts human life.

Ihde's post phenomenology is rooted in the idea of the non-neutrality of the instruments (1979, 74-128), that he takes from American Pragmatism, and is also fused with variational theory, which means that every instrument needs to be considered according to the variation of the lifeworld it affords (1990:43-71). Phenomena of embodiment and perception are also central within this understanding of technoscience (1979:6-11) and are originated in continental phenomenology. The idea of embodiment is directly connected with the idea of hermeneutics (1979:36-37): technologies can mediate human experience with the world according to two main relationships: when the technology acts as a sensing extension of the human we are presented with a relationship of embodiment, whereas when transparency is not achieved we are presented with a hermeneutic relationship: the instrument is being engaged in a critical way to produce a certain type of knowledge. Ihde's favorite example for these kinds of relationship between the knowing ego, the world and the instrument is mainly visual: in the first book he concludes that vision can be easily colonized by an illusionary version of the world completely sutured by instrumental mediation (1979:82-92). For instance, he points towards the vision of the spectator,

produced by cinema and TV, as an example of flowing vision, culturally constructed, that forces images of objectified space and time upon humans (1979:90-91). The idea of technically mediated vision is further explored in *Expanding Hermeneutics* (1999), a collection of essays on vision and visuality in science written over the span of more than 20 years. The central idea of the collection is represented by the fact that the natural sciences have grown into a culture of science that is visualist, and this can be seen by the abundance of visualizations used to provide a readable pattern of data for human understanding and exploration (1999:151-169). Ihde indicates this abundance of visualization as the attempt to provide a visual hermeneutics that wants to mimic isomorphic images (1999:58-60) in a desire to reach full transparency in the relationship between the knowing ego, the mediating instrument and the investigated world (1979:8).

In the 1999' book Ihde ends up providing two different ways of producing a hermeneutic of technoscience: a weak hermeneutic program and a strong version of it (1999:146-150). In the weak hermeneutic program, the duty is to reconstruct accounts of practices in science showing the implicit hermeneutic at play within it. In the strong version of the hermeneutic program, science is always technologically mediated. Mediation is discussed in ways that can open up the visualist evolution of technoscience toward the inclusion of the other senses, toward a holistic idea of a whole body in the process of knowing (1999:185-195). This idea is also explained in *Postphenomenology and Technoscience* (2009:45-61), where a chapter is dedicated to Imaging technologies as a way to visualize the invisible. Here, in simpler terms, the advent of lens technology in Europe sprung the so-called Optical Revolution, which introduced a new form of human vision. The second optical revolution happened with the Radio revolution, that not only amplified a distant world, but made visible waves of light that previously couldn't be seen by humans. To Ihde, these technologies don't inaugurate the era of posthumanism, they simply present a

new relationship between humans, technology and knowledge, that is called *material hermeneutics*: a reflexive reference to human embodiment remains, but is differently located (2009:63-77). The new image produces a readable result translated by the instrument: a material hermeneutic process offered for the human gestaltic vision, a phenomenological hermeneutics. Nonetheless, the strong hermeneutic program can be activated by "giving voices" to the unheard, in a metaphorical but also quite literal way (2009:75-77). This idea of giving voice through hermeneutics recalls the "science wars", which gave to Ihde the inciting incident for his reflection. For Ihde, the need for a post phenomenology of technoscience was arising from the necessity of finding ways to criticize practices and instruments without falling in Luddism or apocalyptic visions of science evolution (2009:5-9). However, it was also necessary to highlight the perils entailed in this visualist version of science that he depicted as an evolution of the camera obscura, seen as an *epistemology engine* (2000; 2006). The *epistemology engine* of the camera obscura represents instrumentally and metaphorically the functioning of the representational paradigm: an external reality must align with an internal representation, and such relationship can only be judged by an external ideal observer – Haraway's God trick (2013). In his critique, Ihde employs a variety of terms to describe the instruments he discusses. These instruments vary widely and originate from different historical periods. His emphasis lies in exploring the connections between humans, instruments, the world, and the process of knowledge production.

However, to empirically ground my work I sought novel ways in which Ihde's thought has been applied, therefore I turned to Human-Machine Interaction Studies, especially developed in the sector of Musicology. Magnusson's (2009) declension of Ihde's relationships between human and instruments proposes novel examples for the

comprehension of the relationship between embodiment and material hermeneutics. While both analogic and digital instruments have inscribed within their materials the epistemological conceptions of what music is and according to which rules (or not) it is produced, the analogic instrument leans towards a form of relationship of embodiment, whereas the digital instruments represent a form of material cognitive extension of the mind. As such, it is a medium that enables a hermeneutic relationship. This means that the digital instrument is an *epistemic tool*: it has inscribed within itself the rules that can afford a symbolic translation operated by the user according to a specific design. Magnusson explicitly concludes with the indication of the simplification he had to use for the purpose of his study, in order to specify the need for a careful understanding of the responsibility that comes with designing epistemic tools. Since the pipeline of data collection and elaboration is interpolated by mediating layers that produce visualization, I propose to read Lidar as an epistemic tool.

As I will illustrate, the history of the development of laser, as well as the idea of operating it for the development of automation in robotics, was not linear. On the contrary, it entails different points in time, ideas, conceptions, availabilities, absences, coincidental emergences and materials, all bundled up together like a matryoshka with an enigmatic smile. I turn towards hermeneutics as the intellectual discipline of interpretation to find ways to open up this neon-colored black-box, and I'll be guided in this difficult navigation by Cubitt's genealogy of the technical practices used in the manipulation of light (Cubitt, 2015). Cubitt's critical interventions will guide further elaborations regarding the weak and strong hermeneutics sustained by, and modified by, Lidar imaging.

Wellner (2020), in "Material Hermeneutic of digital technologies in the age of AI", explains in a compelling manner how and why hermeneutics is necessary more than ever to understand the relationship between humans, technologies and the world. The pioneer of hermeneutics applied to technology were Don Ihde (1990) and Sir Patrick Heelan (1991). While, for the latter, the most important question resided ultimately in understanding if reality is anything but a social construct, Don Ihde focused on building a philosophy of science that can engage with materiality in novel manners. Ihde's perspective emphasizes the inseparability of science from the tools used in its practice, rejecting any notion of superiority or distinction between theory and the instruments that aid in developing it. He refers to this integrated approach as "technoscience", highlighting the essential role of materiality in scientific processes. This perspective enables the consideration of the materiality of virtuality, in contrast to the cybernetic mythology of pure information (Hayles, 1999).

"This is the core of the digitality that separates content from technology, software from hardware, information from device. The hardware withdraws leaving the foreground to the software and the data. In this ecosystem, the virtual is the visible and the physical is the invisible" (Wellner, 2020: 2 Materiality and Digitality). Wellner then reports a passage from Latour (2010), highlighting how his idea of network, while actually very different from the technological variant of the name, represents a useful tool to bring into light once again the material primacy of the infrastructure that allows information to exist, travel and change, as well as the users. And, Wellner goes on quoting Hayles, the same way information is tied to hardware, human cognition is tied to the human body. In post phenomenology (Ihde 1990; Verbeek 2005) the term "embodiment" represents a specific relationship of mediation in which the technology alters the schema of the body, including the device, and experiences the world in a different way. The alteration of the body is also accompanied by a specific material desire, which Wellner modifies for the digital context:

"[…] where the users pursue a 'total transparency' of the underlying infrastructure that enable the manipulation of information, i.e. virtuality. Simultaneously the hardware always needs to be upgraded and it is never sufficient, never fast enough" (Wellner, 2020: 3 Embodiment Relationships). Nonetheless, digital technologies operate only indirectly on the body, and their effects are principally afforded by their cognitive effects. This is the reason why the relationship between humans, technology and the worlds becomes of primary importance: the relationship of material hermeneutics. The hermeneutical relationship is that situation in which the human, through the technology, reads and interprets the world. The essence of the hermeneutic relationship implies that no technological intermediary, be it a map or a photograph, is neutral. All of them carry within themselves a worldview, thus requiring critical discernment. This, according to Ihde, is the effect of 'technological intentionality': all technologies are designed according to certain 'selectivities', and in this way they can direct the user (Ihde, 2015). Verbeek, in *Cyborg Intentionality* (2008) points towards 'composite intentionality', which represents a situation in which the outcome of a technology does not represent the world according to truth, but according to novelty. This novelty is tied to the material aspect of the hermeneutic relationship that connects the technology to the world. Wellner also connects Verbeek variation of the hermeneutic relations once applied to digital technologies to the idea of *trace* developed by Derrida (1978): "It can reflect the active role of a text as a trace that exceeds the act of writing and sometimes even the life of the writer. This is how material hermeneutics works. The text becomes a trace in the world" (Wellner, 2020: 4 Hermeneutic Relations). In the original hermeneutical relationship, 'technology' stands both for the tool and for the result of the tool. Wiltse (2014) suggested to differentiate between 'substrate', for digital materials that carries information inscribed in it; and 'trace', for the information once liberated from the material incubation of the hardware that produces it as such. "This difference maps into what I previously described

as the split between hardware and software, or the invisible (materiality) and the visible (information). The production of information is usually hidden whereas the display of the information gains our attention. In other words, the virtual is the visible and the physical becomes invisible" (Wellner, 2020: 5 Hermeneutic Relations in a digital world). Wiltse, adding a specific reference to the material substrate in the hermeneutic relation signals towards the importance of materiality. Wellner adds to this turn towards material hermeneutics the work of Liberati (2016), who analyzes Augmented Reality and how it affects users, especially when it comes to phenomena connected with attention. Wellner goes back to the original formulas about the ultimate goal of a hermeneutical phenomenology, in Heelan and Ihde. While Heelan doesn't accord much importance to readable instruments (Heelan, 1991), Ihde dedicates long sections to the analysis of digital instruments and how they can be applied in humanities (Ihde, 2009). And his prescribed goal through hermeneutics is to make things talk beyond their established account, as previously mentioned. According to Wellner, a material hermeneutic is more radical than simply understanding values inscribed in technologies (Tripathi, 2018). "Such digital material hermeneutics highlight the need to understand how digital technologies mediate the world to assess the worldview they provide" (Wellner, 2020: 6 Digital Material Hermeneutics). Wellner deployed such revised postphenomenological relations to the analysis of how writing has changed, through the use of cellphones (2018). In the analysis, writing, in the digital era of cellphones that are used as prosthetic registration devices, has fundamentally changed the relationship between humans, technology and the world. Indeed, cellphones are one of the main vehicles with which algorithms write to humans – the example is app notifications. Machine learning algorithms are designed to produce texts, to write texts that can direct human attention and modify their relationship to the surrounding environment. Nonetheless, these texts are the result of two different datasets, one for training and one for the data to be organized in a text, and the encoded

intentionality of this form of writing doesn't entail any kind of care for the user. The user is the one reading the text and loses the agency it originally held in the postphenomenological relation.

The hermeneutic relationship arising from the digital materiality of epistemic tools has been a topic explored especially in the field of architecture. Poulsgaard and Malafouris (2020) definition of digital materiality is tied to the creative process emerging from the interaction of the architect and the layers of software used to modify the design. In their rendition of the extended mind of the architect, in the creative process, the molecules composing the different materials of the hardware are connected all the way through the layers of mathematic calculus and the polynomial geometry afforded by software. Conversely, Voordijk and Scholtenhuis (2022) present a study centered upon the exploitation of 3D modeling and the projection of models in Augmented Reality in the context of projects of civil engineering. The authors describe how radar technology is often used to trace the presence of infrastructure undergrounds, while laser scanning is often used to map the façade of buildings. In both instances, sensing technology is deployed to make visible something invisible to the human eye. Nonetheless, both the generation and the post processing of visualizations is necessarily tied by designed selectivities inscribed within the sensor. A lack of understanding of the limitations imposed by such selectivities can bring forth cases of *epistemic uncertainty*, which means, it may generate false results and induce a form of "blindness" to phenomenological reality in humans.

2.6 Conclusion

In this chapter, the nexus between spatial management techniques, data mining, and the algorithmic processes of sensemaking have been explored, according to the rich literatures afferent to Critical Data Studies, Surveillance Studies and the geospatial lens offered by Human Geography.

Critical Data Studies, with its emphasis on the translation between lived space into the virtual space, constructed through data, offers valuable insights for comprehending and guiding the development of new technologies. However, it tends to fall short when it comes to providing macro-level theoretical explanations. The difficulty in grappling with the affects and effects of visual digital technologies is also evident in the empirically rich productions within the branch of Human Geographies that explores the networked life of images carrying geospatial data. Despite the rich production of new epistemologies of relationality (Maalsen, 2023), the ontology proposed is openly incapable of providing support to answer to the research questions proposed for this thesis. Surveillance Studies, with their political attention to the history of devices and technological techniques at the service of social control, can offer important insights in the gaps left open by the refined genealogies of Critical Data Studies and the empirical evidence offered by scholars from Human Geography. Nonetheless, grappling with philosophical questions that often blur the distinction between surveilling and watching, Surveillance Studies loses focus and fails to provide useful indication when dealing with geovisualities. Human geographers argue that current philosophical positions risk misunderstanding the causes for the effects (Elder-Vass, 2015; Mills, 2018; Rosiek et al., 2020), while it should be noted that a strong claim around non-human agents needs an epistemological foregrounding that would steer far away from seeking answers to the proposed research questions.

In response to these limitations, a turn toward the Post-Phenomenology of technology is advocated in this project. This position is not widely accepted among human geographers, although we are starting to see a rise in the interest for this philosophy and the appropriate methodology, in the analysis of how different technologies constitutes the experience of determined spaces (Ash and Simpson, 2016; Ash et al., 2018b; Hepach, 2021; McCormack, 2017; Revill, 2016).

In addition to that, Post-Phenomenology proves relevant for studying the visual outputs of technology and attending to spatial matters for several reasons. It aids in clarifying human positioning in the digital world, by understanding the lived implications of visual outputs, while critically examining the narratives they support. Additionally, it provides a framework for addressing broader consequences deriving from the deployment of certain technologies, emphasizing the active role of these tools in co-shaping human experiences within specific spaces and times, and through certain materials and determined processes. Post-phenomenology helps uncover overlooked aspects of digital technologies, highlighting their role as mediators in the relationship between people and their environment. It emphasizes that technologies are not neutral objects in the hands of human subjects, but rather mediators, that shape our experience of the world and, as such, should be actively investigated beyond accepted narrations.

Nonetheless, it's also paramount to highlight the weaknesses of post-phenomenology, a kind of philosophy that shows its limits in relating to socio-temporal and performative dimensions of the phenomenological experience. For this reason, a suggestion to introduce metaphors from dance, theatre and music has been advanced to account for the non-static aspects of using technology (Coeckelbergh, 2020). Similarly, a notion of choreography has been introduced in Human Geography to account for the relationship

between the social, temporal, and movement related side of experience (Baker et al., 2022; McCormack, 2008; Rubidge, 2011).

The present study will provide a first effort in bridging a geospatial perspective to the digital materialities that generate, and are in turn produced by, Lidar imaging, following a call for sustained geospatial critical prospective, specifically in the realm of remote sensing (Bennett et al., 2022). Thus, this enables to offer: in the first place, a description of the imaginary sustaining online deployment of lidar imaging; secondly, a reading of the animation of collected Lidar data on screen as augmented mapping; without forgetting how the interplay of materials and processes composing the tool projects conceptualizations of space and time with epistemic implications.

Chapter 3

Methodology

3.1 Introduction

In the quest to comprehend the production of geospatial knowledge through the mediation of new technologies, particularly focusing on how the epistemic tool of Lidar shapes the hermeneutical relationship that ties it to users and environment, this project turns to the role of Lidar sensing, in the making of driverless cars. Autonomous driving stands at the nexus of diverse yet interconnected inquiries involving privacy, ethics, politics, sustainability transitions, and the intricate relationships between humans and non-human agents, among others. Originating from the surveying process and the unique visual/spatial characteristics of Lidar, alongside other imaging sensors, this project conceptualizes driverless cars as geo-visual productive machines. It proposes a mixed-method empirical study to unravel the patterns of power inscribed in the materiality of the visual-digital Lidar sensor, aiming to shed light on the intricate dynamics at play in the technological mediation of space. As foregrounded in the Introduction, the infinite play of mediation is methodologically relevant in this project too, as my access to Lidar sensing as an epistemic tool is mediated by the information made available by the makers.

The prevailing apprehension, both in mainstream discourse and academic circles, regarding Connected and Autonomous Vehicles (CAVs) revolves around ethical considerations related to human/non-human interactions and the unpredictable outcomes of algorithmic decision-making within the inherently messy real-world context. However, this project takes a divergent path, aiming to scrutinize the construction of machine vision within driverless cars from a different angle — specifically, exploring how the visualizations generated by sensors redefine the interplay among perception, space, and knowledge.

Furthermore, Lidar sensing generates visualizations of space that possess distinctive aesthetic qualities, existing within the nebulous realm where images and spatial data

converge in code, still confusing many scholars from different fields, as already seen in the previous chapter.

The making of the driverless car, functioning as a surveying entity that produces visualizations influencing the networked urban field, provides a lens, although merely contingent, to examine practices of data collection, the generation of meaning, novel configurations of knowledge/power relationships through machinic vision, and the reconfigurations of coded spatialities.

The driverless car, equipped with an array of optical and spatial sensors, emerges as a focal point, catalyzing attention in the exploration of how geographical knowledge is produced — especially through geovisualities, mediated by new technologies, that result from human/non-human encounters. The urban space becomes a laboratory where the boundary between business and research becomes blurred. According to advertisements and press narratives, this technology, with its "disruptive" qualities, is slated to revolutionize the industry permanently, subsequently reshaping how planning and mobility infrastructures are deployed within the city.

In the endeavor to elucidate how Lidar is both produced by and contributes to the formation of a normative conceptualization of space, the thesis articulates three primary objectives:

- To systematically map, code, and decipher the imaginary propagated and reinforced through Lidar imaging on makers' websites.
- To scrutinize the intricate relationship between the process of data collection and the subsequent creation of visual representations.
- To delineate the spatial and temporal dimensions engendered by the utilization of Lidar imaging and its online deployment.

These goals collectively form the foundation for a comprehensive exploration of Lidar's multifaceted role in shaping not only how space is perceived and managed, but also how new conceptualizations of space, time and the human subject, as a technoscientific designer and user, can be more broadly connected to existing cartographic tendencies.

In the pursuit of constructing a precise depiction of Lidar imaging, taking inspiration from Goffe's reflections on the cartographic impulse (2020) and drawing insights from sociologist David Beer's discourse on the data imaginary (2018), I opted to amass an archive of Lidar images prominently featured on companies' websites (Cyr et al., 2009; Li and Xie, 2020; Vilnai-Yavetz and Tifferet, 2009). This archival collection serves as an attempt to systematically chart the discourse that surrounds these visual materials and, conversely, is upheld by them. Consequently, the research pivots from a focus on knowledge communities to an exploration of the epistemic tool itself (Ihde, 1979; 1990; Magnusson, 2009), as the device that produces certain images, result of a pipeline from data to visual output. The methodologies adopted became tailored to scrutinize visual-digital technologies (Lapenta, 2012; Leszczynski, 2019) and will be described in detail in the following paragraphs.

In delineating the journey of this research, this chapter unfolds in a structured sequence. Commencing with an exhaustive exploration of the data collection process, the steps involved in amassing a rich and diverse array of Lidar images are unraveled. This initial section is crafted to provide transparency and depth, offering readers an insight into the nuances of assembling the primary dataset. Following this, the chapter transitions into a portrayal of the data analysis phase, which is methodically compartmentalized into discourse analysis, film analysis, and a strategic engagement with media archaeology, to

navigate the veiled realms of industrial secrecy. Each analytical lens is applied to unveil distinct layers of meaning embedded within Lidar imaging. Then, the chapter turns to the distinctive features that define this project, emphasizing the creation of an ephemeral archive housing Lidar's online manifestations and underscoring the significance of embracing uncertainty as a productive outcome in research. Subsequently, a candid exploration of the encountered difficulties and obstacles unfolds, providing an account of the project's developmental challenges. The chapter concludes with a reflective discussion encompassing ethical considerations surrounding research participants and a nuanced exploration of the researcher's positionality within this investigative landscape. This sequential structure aims to provide a tour within the different dimensions of the research process, fostering a comprehensive understanding of its methodology, challenges, and ethical underpinnings.

3.2 Internet Survey and Content Analysis

Between June 2020 and April 2021, an internet-based survey was undertaken to understand the role of the deployment of geovisualities produced by lidar within the brand image building, developed by the very companies producing them, on their websites. The larger span of time required by such a process is justified by the difficulties in grappling with an extremely varied landscape composed of start-ups rising and burning down, acquisitions, mergers, lobbying, and sudden disappearances.

In recent years, a proliferating ecosystem of emerging entrepreneurial endeavors involved in high-risk financial investments for the development of technological devices and services (Cassetta et al., 2017) has created a general enthusiasm (Frederiksen and Bren, 2017) that has had to face the reality of the high rate of failure encountered by most companies within five years of their creation (Cantamessa et al., 2018; Akter and Iqbal,

2020). Especially in the transport and mobility sectors, the influx of new ideas has been undeniable (Cassetta et al., 2017), while posing new questions of governance at a state level and of regulating policies at a local level (McNeill, 2016). In fact, start-ups, in their attempt to establish themselves as capable of selling stock to raise funds, have forged for themselves a model that prepares them for future mergers with other companies (Brown et al., 2020). These financial moves have created so-called "unicorns", private companies capable of raising more than a billion dollars in net worth; nonetheless, such financial moves cannot protect companies from failure if they are incapable of producing sustainable development plans for their operations (Sornborger, 2021).

Following the example of Dodge and Kitchin's seminal work *Mapping Cyberspace* (2003), the first goal of the survey is to determine the importance and meaning of using Lidar imaging, as it occupies screen space (Dou and Krishnamurthy, 2007) in the brand image building (Rappaport, 2007) online. A secondary aim was to chart emerging visual tropes, developed through the showcasing of lidar imaging, starting from their aesthetic appeal and with the aim of circumscribing the discourse they sustain and reinforce. Nonetheless, Chapter Four will be based on visual content analysis (Leszczynski, 2019; Rose, 2022), whereas the discourse analysis, with the coding and decoding of the visual rhetoric (Salerno, 2014; Scott, 1994) inscribed in the deployment of lidar imaging, will be fully presented in Chapter Five. Both of these passages are necessary to define the significations sustained by lidar imaging.

The objective of this first part of the thesis is, consequently, to describe the *imaginary* surrounding the deployment of lidar geovisualities in the development of the driverless car. Accounts of the *imaginary* represent a well-established practice in the sociology of phenomena arising from the diffusion of algorithmic practices (Bucher, 2019).

David Beer (2018) charts a critical version of the idea of the "data imaginary", mediated by Taylor (2004), according to which data analytics, the underlying rationality of the imaginary, present a powerful tool that is capable of practically shaping infrastructures and the practices that infrastructures make possible with wide consensus on a social level. For Beer, the imaginary is what the social body can do within the affordances of data analytics. Beer's conceptualization of the imaginary is aligned to the critical choices presented in this thesis, as it aids in dismantling the "cyberbole" (Woolgar, 2002), the artificially constructed linguistic hype, around machine learning and Artificial Intelligence. Especially when it comes to locative algorithms, we really are dealing with just a set of instruction to compute a task (Hunger, 2023). This assumption doesn't make the epistemic tools in question any less powerful.

The survey methodology was composed of two different moments. The first one, the longest and most complex, related to identifying the companies to include in the survey. The difficulty in doing this was once again arising from the very commercial landscape that served as the backdrop for this survey. The intrinsic speed of the evolution of this technological market represented a great challenge to tackle while providing a stable and meaningful sample.

The second step of the survey involved manually searching the individual websites for every firm, scanning the pages for geovisualities, and noting their presence, position, and role in the visual and textual bodies occupying screen space on the site. The results for the eighty companies charted were registered in a table, whereas a screenshot of all geovisualities singled out was screen-grabbed and stored in an archive (see Appendix A), along with relevant snapshoots from videos.

3.2.2 Website Sample

The eighty companies that were included in the survey represent a variety of commercial stakeholders in the technological niche focused on developing autonomy along the multilayered automotive industry supply chain. Therefore, some of them are hardware providers, while others focus on software. Some of them are instead committed to producing the whole stack, while others provide punctual solutions to specific problems in the autonomous ecosystems.

Some of these companies have made quite a name for themselves, either for their prestige or for their net worth. They produce parts or provide services to the biggest vehicle brands. Others are smaller in the scale of their operations. All the companies included are connected to the automotive supply chain; lidar companies involved in different technological fields—in the development of augmented visual instruments for the visually impaired or for different kinds of mobile robotics—were not included in the list. They are ordered in alphabetical order, in a table presented in Chapter Four, and the white lines in the table represent companies that are no longer operative. They were kept on the list for methodological completeness, although they were replaced in the count with other currently working companies so as to maintain a substantially populated sample. All the modifications are listed in the table and in its legend.

Geographically speaking, most of these firms are based in the USA. Some smaller companies from Europe, Turkey, and China are included in the list, but because of the language barrier, information extraction was limited.

All the businesses included in the survey have been manually charted, drawing on personal knowledge accumulated while charting start-ups for interviews, and a detailed description of this part of the research will figure later in this chapter, and consulting financial articles regarding the lidar market.

3.3 Multimodal Discourse Analysis

In the pursuit of unraveling the discourse propagated and fortified by Lidar imaging, a pivotal shift occurred in the project's trajectory following the compilation of the table outlined in Chapter Four. This table served as a crucial lens through which the presence and prominence of Lidar imaging on public companies' websites were elucidated, by counting appearance and the site of such appearance. However, as will be shown, while the presentation of quantifiable results offers a tool to frame the problem, it falls short as a comprehensive data analysis methodology capable of addressing the specific research questions that constitute distinct moments within the overarching objective.

This marked the initiation of the second stage in the analysis of the amassed data—a stage that unfolded chronologically and methodologically after the data collection and content analysis, focusing on an examination of the discourse sustaining Lidar imaging. The objective was clear: to unravel the formal aspects intricately woven into the creation of this specific manifestation of digital mapping.

In selecting data sources, attention gravitated towards official company websites, regarded as repositories of rich and heterogeneous content encompassing text, images, videos, and interactive elements. The decision was motivated by the ambition to amass sufficient data to facilitate a robust qualitative multimodal analysis (Pauwels, 2005; 2012), aligning with established research projects of similar magnitude. The sample was selected through cross-referencing rankings of the fastest-growing, most valuable, or market-leading tech companies offering lidar imaging for driverless cars.

The criteria for selection were stringent — companies had to feature in at least two lists provided by financial and technology journals, coupled with public positioning in the stock market, indicative of a degree of success in the field (Anlitycs Insight 2022; CBInsights 2018; Coldeway 2017; Retours 2017). Lidar start-ups that ascended to this

role earned the moniker "lunicorns," a portmanteau of the venture capital term "unicorn" and the initial letter "l" denoting "Lidar."

This selection process led to the identification of eight major entities. However, as the thesis unfolds, it becomes apparent that the volatility of the field has altered from the initial configuration, with mergers, bankruptcies, and changes in the main product manufacture and advertised features.

The data collection phase built upon the archive established through the previous form of data analysis. However, with a subset of the population selected for qualitative methodology, in the way detailed in the above paragraph, a more comprehensive collection approach was undertaken, employing a method termed multimodal clickthrough — an adapted version of the walkthrough method used for the systematic study of apps (Light et al., 2018), following the footsteps of De Seta and Shchetvina (2023).

This method involved an in-depth exploration of corporate websites, navigating through links, videos, tech demos, blog posts, press releases, white papers, and published patents.

Similar to the previous step in data analysis, there was a special focus on page hierarchy, considering how the dissemination of information, or its absence, added nuance to what was presented to the web user's gaze.

The data amassed during this extensive exploration encompassed two aspects: primarily visual content — web pages, including graphics and videos, inscribed within enclosing

text modifying connotative meanings — and descriptive notes capturing general impressions, thematic coding, and close readings.

A notable limitation of this study lies in the fact that a significant percentage of the companies examined are based in Western countries. Although a company based in China was included, my comprehension of the displayed content was markedly limited.

The culmination of several months of data analysis, involving multiple iterations and discussions of provisional results, is encapsulated in two research diaries and over 450 screenshots, Appendix A exhibits all the homepage screenshots from all the 80 companies. This extensive dataset underwent a streamlining process for a comparative analysis rooted in multimodal discourse analysis. The iterative refinement of concepts during the data collection phase paved the way for a focused analysis aimed at extracting overarching conclusions about the visual rhetoric supporting Lidar imaging. While a pilot study was conducted in July 2020, none of the preliminary work is included in this thesis due to the immaturity and lack of grounding in both the sample and the codes.

The analytical process involved qualitative coding of multimodal data to identify repetitions, prosodies, similarities, differences, and thematic clusters. Embracing a multimodal perspective, the analysis transcended mere text and images, embracing the interplay concerning framing, tone, rhetoric, and layout. Self-reflexive field notes and archived screenshots played a crucial role in accommodating the fluidity of websites, countering the ephemerality of the appearance of Lidar imaging, subjected to frequent updates.

The outcome of this comprehensive analysis was the identification of emerging themes distilled into seven major categories, each contributing to the articulation of a cohesive technoscientific imaginary. The project uncovered distinctive features of the Lidar imaginary, elucidating how different visual registers collectively contribute to it. This thorough exploration not only adds depth to the understanding of lidar imaging and its online representation, but also serves as a valuable contribution to the broader discourse on the advertising of technoscientific tools within the digitalization of the urban site.

3.4 Film analysis

As articulated earlier, one of the primary goals of the initial data analysis was to delineate the geographical boundaries of a somewhat elusive subject that resisted straightforward geographical inquiry, despite its connection to GIS tools and the production of spatial relationship visualizations.

The subsequent analytical step, charting an alternative path, yielded results that mapped how these sensors permeate the digital public sphere. This involved deciphering not just what manufacturers purport these tools to achieve, but also discerning the implicit influence of how these tools are effectively deployed, complete with biases and underlying assumptions. However, this phase did not unveil the intricacies of the functioning of these laser digital eyes[9].

It was during this realization that the limitations of discourse analysis became apparent. While adept at dissecting the interplay between visual elements and verbal prosodies, it fell short in extracting meaningful insights from the presentation of lidar as a moving image representing space. Recognizing this gap, I follow the call of human geographers,

[9] "Laser digital eyes", here and in other places in the thesis, is used as a metaphor for Lidar sensors. As we will see in detail in Chapter Seven, Lidar sensing is based on digitally translating laser pulses of light.

particularly those on a quest for new geographical philosophies in the digital age. They underscored the potential enlightenment that interdisciplinary theoretical frameworks and methods might offer when grappling with the nuances of the moving image (Roberts, 2013; Wilson, 2017).

Drawing from my background, I found myself turning to film theory. Film theory, with its expansive scope encompassing various theoretical perspectives, became a pertinent methodological lens for inquiry. Given the unique qualities of animation and its role in portraying geographical knowledge, I delved into the semiotics of cinema, particularly the work of Bertetto.

Bertetto's approach stands out for its projection of linguistic tools, rooted in a cognitive understanding of the mind and its externalization through aesthetic technologies, onto the visual materials presented by cinema. This formalist approach, originating from the Russian Cinematic Vanguard (Montani, 2019), places paramount importance on a film's form or structure, scrutinizing elements like light, sound, and camera angles in their contribution to meaning-making (Bertetto 2003; 2006; 2010). This analysis, given the spatial characteristics of Lidar, is also informed by attention to animation (Cubitt, 2015) and how it impacted geospatial techniques (Wilson, 2017).

In executing this form of analysis, with a focus on videos embedded in start-up websites often concealed in webpages or subjected to heavy rotation, I turned to the YouTube channels of the start-ups forming my smaller sample of "lunicorns." Over a six-month period, I watched every video on the scrutinized company's YouTube channel, noting the main codes identified in the prior analytical step. Following this initial discourse code analysis, I opted for an in-depth filmic semiotic analysis of videos prominently featuring

Lidar imaging, guided by the criteria of presence and prominence, mirroring the analytical approach of my initial data analysis.

This phase of data collection and analysis marked a critical turning point in the overall trajectory of the thesis. The examination of the moving image, treating it as both a piece of film and a piece of animated cartography, unveiled novel liminal spaces of meaning and critical inquiry that demanded thorough dissection. Recognizing the need to deepen the analysis, I turned to the principles of media archaeology, for its ability to account for the evolutions of theories, materials, and techniques. This approach, coupled with an acute awareness of the dialectic of visibility and invisibility in the hermeneutic relationship between humans and epistemic tools, concepts that form the core of Post Phenomenology, as seen in the previous chapter, provided a valuable framework.

3.5 Media Archaeology

Media archaeology is dedicated to unraveling the intricacies of new and emerging media (Huhtamo and Parikka, 2011). Its unique approach involves an examination of the past and a critical interrogation of prevailing narratives within popular commercial media, including film and television (Elsaesser et al., 1994; Elsaesser, 2004; 2004b).

Positioned at the intersection of materialist media theories and an appreciation for the obsolete and forgotten, media archaeology has gained significant traction since the 1980s, fueled by the emergence of new cultural histories. In adopting a non-linear and theoretical approach to media history, this field explores breaks and non-continuities in the epistemological conditions that signal the emergence of media (Cronin, 2011; Goddard, 2015).

As a method of intellectual inquiry, media archaeology places a distinct emphasis on non-human agency (Huhtamo, 1999; 2006), focusing on the operations of media entities that often transcend individual perception due to their scale, duration, minuteness, or swiftness. This approach involves a comprehensive investigation into textual, visual, and auditory archives, as well as collections of artifacts (see Figure 2 for an artistic variation on this idea), shedding light on both the discursive and material manifestations of culture (Ernst, 2016; 2017).

While media archaeology may not have formally organized itself as a discipline, it has evolved into an accepted research method. The method of media archaeology research entails understanding new and emerging media by examining the past, critically scrutinizing dominant narratives within popular commercial media, probing for breaks and non-continuities in the epistemological conditions of media emergence, stressing non-human agency, and probing the workings of media that elude individual perception. This involves a thorough exploration of multimodal archives, along with collections of artifacts, with attention to both discursive and material manifestations of culture (Fickers and Oever, 2022; Roberts and Goodall, 2019; Van der Heijden and Kolkowski, 2022).



Figure 2 Daniel Canogar's "Gear – Latencies Series", 2021, my picture from the exhibition Reverberations at Galerie Kornfeld, Berlin, 2021.

Media archaeology, within this project, emerges as a mean to transcend the shroud of silence and industrial secrecy enveloping Lidar imaging.

The lack of transparency resulting from non-disclosure of inventions can lead to opaque economical dynamics (Guo et al., 2016). While enhanced trade secrecy may shield existing innovations, its impact on future innovation remains uncertain, potentially dampening inventors' productivity and impeding long-term progress.

The protection of algorithms under trade secret laws contributes to algorithmic opacity, making it challenging for researchers to comprehend their workings and assess their impact upon democratic processes (Lu, 2020). This opacity not only hinders scientific understanding but also has broader implications for public trust in emerging technologies, corporate accountability, and potential infringements on privacy and other human rights (Levine, 2007).

Drawing from the discourse analysis developed in earlier stages of the research, a methodological shift was made towards media archaeology. This involved exploring historical texts, guided by an awareness of the distinct elements constituting the Lidar sensor, available through published white papers and a survey of scientific papers. The research unfolded through historical discontinuities and fortuitous convergences, tracing the evolutionary trajectory of this scientific visualization tool to its current state of the art. However, a notable limitation emerged in the examination of the algorithms within the software segment of the visualization stack.

While industrial secrecy and its consequent dearth of data present a rich source for defining the epistemology governing Lidar development for driverless cars, they simultaneously pose a substantial obstacle to research. This challenge, as underscored in previous stages, persisted through this phase. Acknowledging the potential impact of melancholia on the rigor of research, particularly in media archaeology where the

researcher's positioning and self-reflexivity are crucial, the endeavor to overcome this obstacle was characterized by a persistent and in-depth survey of ongoing debates within the scientific community in data science. This involved consulting papers, conference proceedings, and educational materials constituting the syllabi of university courses in machine learning.

This dual approach, combining media archaeology with rigorous scientific validation, aimed to refine and balance the analytical process.

3.6 Practices of archive

Practices of the archive in media studies encapsulate the methodologies through which media scholars and researchers interact with archives, utilizing them as rich sources of information and evidence. This engagement with the archive reveals an understanding of its role as a regulated, connecting, and converging apparatus, emphasizing the social constructs embedded within its contents. Within media studies, the archive becomes a versatile tool employed for the exploration of media effects, histories, and cultures.

Crucially, the landscape of media studies incorporates evolving practices such as web-archiving and social media archiving (Bountouri and Giannakopoulos, 2014; Cannelli and Musso, 2022; De Vletter, 2019; Stewart and Breitwieser, 2019; Vlassenroot et al., 2021). These contemporary domains of research involve practices encompassing selection and collecting, as well as considerations of access, use, reuse, preservation policies and privacy concerns. Archival research can also combine contemporary collections with the examination of historical documents like old newspapers and past publications.

The importance of archival research transcends disciplinary boundaries, catering to a diverse audience that includes research professionals, archivists, journalists, media professionals, researchers, historians, genealogists, knowledge managers, legal professionals, and beyond.

Engagements with different kinds of archives serve as a foundational element for understanding the ways in which archives shape our perceptions of media history, culture, and effects.

In his book *The Data Gaze: Capitalism, Power and Perception* (2018), David Beer analyzes the idea of the data gaze and its impact on society.

Central to Beer's exploration is the utilization of the archive as a tool for scrutinizing the diverse knowledge entwined with data analytics. His analysis reveals that the envisioning of these analytical processes plays a pivotal role in the ascendance and prevalence of data mining and elaboration, across various professional and social hierarchies. Beer's primary concern revolves around comprehending the pervasive influence of data-led, data-driven, and data-reliant forms of capitalism within both organizational structures and everyday life.

Beer's work aligns with the practices of the archive, leveraging this rich source of information and evidence to unravel the fractal ramifications of the logic and methods of data analytics. His examination regards the construction, creation, and imagination of the gaze of data analytics within the industry responsible for its proliferation. The envisioning process emerges as a crucial step in comprehending the practical applications and implications of these processes and imaginations.

Beer utilizes the archive strategically in his book to buttress his argument regarding the industry-driven construction and envisioning of data analytics. He constructs a public available archive, encompassing a broad spectrum of different data, including social media data, administrative data, and historical data related to the evolution and accumulation of both small data and big data. This collection features diverse sources, ranging from academic articles and books to interviews and blog posts. Thus, the archive presents itself as a repository, offering insights into the impact of data analytics on society and the processes by which data is constructed, created, or envisioned by the industry at its helm.

A pivotal aspect highlighted by Beer from Derrida's (1996) work is the enigmatic notion of the "archon". The archons, those that wield and contain power, played a decisive role in determining the contents within the archive and how they were categorized and accessed. They wielded control over the narrative that could be constructed using the archive, shaping the official site of accumulation of traces. According to Derrida, true power resides in those who can control the dataset, in updated language, as information and metadata accumulate[10].

In Appendix A, I introduce my own initiation into archival practices. This archival endeavor holds the potential to stimulate theoretical and analytical reiteration, foster novel collaborations, and foreground heretic and indigenous epistemologies (McCormack, 2010; Parisi, 2021; 2021b; Radcliffe, 2017; Schwanen, 2018) for future iterations of the present project.

3.7 On uncertainty

[10] For a similar argument around archives and institutional power see Mbembe (2002).

Uncertainty plays a big role in this project, on many different levels: theoretical, methodological, and practical. On a theoretical level, as the magistral work of Louise Amoore demonstrates, uncertainty is the conceptual category against which risk management technologies as a communicative and productive epistemic background have been put in place (2013:7). It may be worth checking out the passage in full:

> The principal technology emerging across the contemporary domains of security and economy is one of risk. The politics of possibility sees a seemingly limitless series of bodies, populations, spaces, buildings, financial transactions, tickets, movements, shapes, and forms divided and fractionated according to degrees of risk. This is not to say, however, that we live in a "world risk society" in which potentially catastrophic and uninsurable risks proliferate. Instead, following a critical body of scholarship on the discourses and practices of risk, risk is a construction, a "way in which we govern and are governed." As these critical risk studies remind us, risk cannot be isolated as a tangible entity or event, for it is performative—it produces the effects that it names. Despite national security strategies that claim "we are entering an age of uncertainty," it is not the case that observable new risks have come into being; what has occurred is that society has come to understand itself and its problems in terms of risk management. What matters is not so much a question of whether or how the world is more dangerous, more uncertain, or less safe but how specific representations of risk, uncertainty, danger, and security are distinctively writing the contours of that world. To consider risk as a means of arraying
>
> and acting upon possible futures is to engage with the practices that are enacted in the name of managing risk and uncertainty.

On a methodological level, uncertainty impacted this project on two levels: a) access; b) the impact of the pandemic in the technological milieu of Oxfordshire. Both of them were taken into account, as I kept a research diary on access progress, while registering how the

pandemic impacted my fieldwork. Parts of these insights will be shared later in this chapter.

The "Uncertainty Principle", proposed by Gary T. Marx and Keith Guzik (2017), articulates the fluidity and contingency inherent in technology and social control. This principle posits that technologies and social control are not fixed or predetermined; rather, they are shaped by an array of factors, including context, interpretation, and improvisation[11]. It acknowledges their multistable nature, meaning that their significance is molded by the context in which they operate.

Illustrating this principle in action, consider social media platforms. Designed to be multistable: their meaning is shaped by user contexts, allowing for unintended consequences. Similarly, technologies created for specific purposes may inadvertently be used for others. Artificial intelligence, intended for efficiency and automation, can perpetuate bias or reinforce existing power structures.

The concept of technology trickle-down functionality is related to the Uncertainty Principle, as it highlights the fluidity and contingency of technology and its unforeseeable consequences on society. Technology trickle-down functionality refers to the idea that technology developed for one purpose can be adapted and used for other purposes (Kalluri et al., 2023). An important example of this will be provided in Chapter Eight of this thesis.

On a macro-theoretical level, Don Ihde's "intentional fallacy" (2006b) is at the core of the Uncertainty Principle, how it has been posited by the fathers of Surveillance Studies.

[11] It should be noted that Marx and Guzik enlist five types of uncertainties connected with technologies and social control, these are: uncertainties of functioning (sometimes things go wrong), uncertainties of intended function (the one pertaining to ambiguous design), uncertainty of consequences (sometimes technologies rebel), uncertainties of context (people can use things for unintended purposes), uncertainty of context (the environment may overwhelm the tool).

Intentional fallacy challenges the notion that the meaning of a text or artifact can be solely determined by the creator's intention. Ihde contends that the designer's fallacy — believing that the intended use is the sole meaningful use — neglects unintended uses and user appropriations of technologies. His theory emphasizes that technologies are "multistable," their meaning is thus shaped by usage context. The intentional fallacy challenges the idea that a creator's intention alone determines the meaning of a text or artifact, highlighting the significance of understanding how users appropriate technologies for their own purposes.

Methodologically, the intricate interplay of theoretical concepts such as the Uncertainty Principle and the intentional fallacy manifests in this research through the challenging task of assigning direct intentionality to the deployment of Lidar imaging online. This approach, in the attempt to disentangle intent from consequence, echoes through the fabric of my research results, offering a perspective that acknowledges the multistable nature of technology and its implications. However, as the critical narrative unfolds in subsequent chapters, the inevitable influence of my own positionality and background becomes more pronounced. The transition from descriptive to critical analysis is marked by an explicit exploration of how my unique identity shapes my perspectives and critiques. This attempt at transparency underscores the commitment to self-reflexivity, acknowledging the web of influences that converge in the research process.

This conflicted embrace of uncertainty, threaded through the fabric of my research, finds explicit recognition in the concluding chapter. It is articulated not merely as a challenge but as a recommendation for researchers in both social science and engineering. The acknowledgment of uncertainty is presented as a generative site —a fertile ground for the emergence of novel technological and theoretical instances. In encouraging this

perspective, the conclusion advocates for a positive reinterpretation of uncertainty, portraying it as a catalyst for innovation.

3.8 Exigencies to the original research plan

The original proposed methodology was comprised of three main moments: elite interviews (Aberbach et al, 2002; Goldstein, 2002; Harvey, 2011), to access engineers developing lidar systems and chart their knowledge community (Turnbull, 2000); to be further explored through ethnography (Uotinen, 2010; Atay, 2020) of experts' conferences and panels. Visual analysis of Lidar imaging obtained through the first two moments of research represented the last part of analysis intending to define the formal aspect of this kind of visualizations in the site of their making production.

Structured upon a tripartite methodological strategy, the research design wanted to unravel the intricate role of digital mapping in shaping the landscape of autonomous driving. At its core, the study aimed to address three pivotal research questions:

How is geographical data produced by experts through machine vision? What kind of geometries of space emerge through this form of knowledge production? What are the effects of technological articulations of space in the context of evolving power relationships in the digital urban site?

Answering these questions would have been the hinge for a nuanced understanding of the relationship between data and their visual organization within map-like visual mediators. Particularly, the research questions wanted to delve into the crossroads where productive power and technology intersect, illuminating the dynamic interplay between technological processes and the exertion of power. To provide tools to critically navigate the complex terrain where digital mapping influences, and is influenced by, the evolving dynamics of autonomous driving.

Two main exigencies undermined the plan. The first one, was the emergency represented by the COVID-19 pandemic. The pandemic undermined the possibility to participate to conferences and presentations. Nonetheless, I followed the digital ones that were open to a wider public, but it was impossible to collect the necessary amount of data to make any significant academic contribution. The second one was the denied access to the experts working on the technology. Knowing the difficulties in accessing elites, especially those connected to mobility automation (Hopkins and Schwanen, 2022), I had produced a very detailed list of labs, start-ups and businesses working in the field, in Oxfordshire especially, but also in UK and Europe. After having completed the CUREC checklist, I started contacting via e-mails gatekeepers, and initially I had the luck to digitally interview two key perception engineers in the company constituting my main case study, between October 2020 and January 2021. Initially they accepted to do follow up interviews, and also responded keenly to my suggestion of sharing screen-shots, images and links. After this first successful phase, all contact was kindly, but firmly, shut down, and snowballing stopped. Moreover, participating to digital conferences, I realized that the data collected this manner was coherent with the kind of discourse that conference panelist proposed during public talks. Nonetheless, I kept on contacting gatekeepers, from January 2021 onwards, but without any success. However, during those months, I also conducted pilot interviews with fellow researchers deploying Lidar in their research. The kind of data I collected through all these interviews gave me cues into the different ways in which the technology was being approached and conceptualized by different researchers, according to their main goals. I will draft a paper on this insight, based upon Levitt's book on optical battles in France modern era (2009). In total, I interviewed ten researchers from different fields, and seven perception engineers. These difficulties obligated me to reflect upon the ties between secrecy – in this case, industrial and

commercial secret – and knowledge (Stabile, 2007), and how to extract meaningful answers to my research questions despite challenges.

Before ultimately deciding to move on from this set of research questions, I embarked on an endeavor to find answers by employing social network analysis. This decision was commanded by a desire to navigate the gatekeeping tendencies within the knowledge communities I was trying to deal with. This involved manually scraping 150 tweets from the accounts of 20 companies and relevant figures engaged in Lidar imaging, actively publicizing their efforts on social media platforms. Due to limitations in the Twitter API, I resorted to manual web scraping and even developed a Python program to automatically extract social media data containing the keyword "lidar." However, the automated scraping yielded a notably noisy dataset, rendering modeling attempts fruitless. Even when modeling the manually scraped data, the results proved less than satisfactory, prompting a realization that digital methodologies may not always be the most suitable. This insight is particularly relevant in a domain marked by communication practices that simultaneously emphasize differentiation among peers while affirming membership to scientific knowledge. The validity of this hypothesis was reinforced through workshops and conferences where Lidar practitioners discussed the challenges of employing network theory in a field characterized by nuanced communication practices, in which not always “relation”, as a fundamental ontological entity, is relevant.

3.9 Ethical Considerations

Ethical considerations constitute a vital dimension of qualitative research, demanding meticulous attention to various principles. As emphasized by the University of Oxford's

ethical guidelines (CUREC)[12], the centrality of ethical conduct in research cannot be overstated. In this context, it is imperative to explore specific facets that underscore the ethical framework in qualitative studies.

First and foremost, the principle of informed consent assumes paramount significance (Bernard, 2017:112; Denzin and Lincoln, 2011:36; Dobrick et al., 2018:93; Hesse-Biber and Leavy,2010:180; Merriam and Tisdell, 2015:188). Participants must not only be fully acquainted with the nature of the research but also engage voluntarily, armed with comprehensive information about the study's objectives, methodologies, and potential risks or benefits. Crucially, participants should retain the right to withdraw from the study at any juncture.

Respect for participants emerges as another cornerstone. Researchers must navigate with sensitivity, acknowledging and appreciating the diverse needs, values, and beliefs of their participants. This necessitates a vigilant self-awareness, guarding against the imposition of personal biases or assumptions that could inadvertently influence the research (Hesse-Biber and Leavy, 2010:118).

Confidentiality and privacy stand as ethical imperatives in qualitative research. Participants must be assured that their personal information will be held in strict confidence, with a commitment to preserving their privacy throughout the study (Dobrick et al., 2018:122).

Anticipating potential harm to participants is an ethical responsibility that demands proactive consideration. Researchers must meticulously assess potential risks, particularly in terms of emotional distress, and implement measures to mitigate these risks. Furthermore, a contingency plan for providing support and resources to participants in the event of harm is a requisite ethical safeguard (Merriam and Tisdell, 2015:188).

[12] https://researchsupport.admin.ox.ac.uk/governance/ethics last accessed 25 September 2023.

A nuanced understanding of power dynamics and privilege is pivotal. Researchers must critically examine their own biases, recognizing how these might manifest in the research process. Vigilance against exploitative relationships between researchers and participants is essential, with concerted efforts directed towards prevention (Denzin and Lincoln, 2011:102).

Ultimately, ethical qualitative research stands as a beacon for producing findings that are not only meaningful but also impactful, underlining the profound responsibility that researchers bear in their quest for knowledge.

In alignment with the ethical principles articulated, the present research rigorously adhered to a comprehensive framework ensuring the rights and well-being of all involved parties. Each interaction, including emails and cold contacts, was preceded by obtaining informed consent. Prospective participants were provided with a succinct document summarizing their rights, alongside a clear delineation of the research's scope and purpose. While these procedural measures were essential for upholding ethical standards, they inadvertently introduced challenges in cultivating trust among participants. These protocols, though potentially hindering initial rapport, underscored a commitment to ethical conduct throughout the research process. The deliberate effort to prioritize transparency and participant autonomy aimed not only to adhere to ethical guidelines but also to establish a foundation of mutual respect and integrity in the research engagement.

The experimental part of the research, rooted in the scraping of social media data and subsequent analysis using social network software, underwent recalibration, ultimately leading to its abandonment. This decision was driven by a confluence of considerations. Firstly, the data set derived from scraping exhibited substantial noise, compromising the reliability and interpretability of the findings. Secondly, the chosen methodology

diverged significantly from the preferred theoretical framework guiding the broader project. Attempting to force-fit the concept of relationality among the scraped accounts was deemed incongruent with the nuanced theoretical underpinnings chosen, risking the imposition of preconceived hypotheses on empirical data (Brughmans and Peeples, 2023:26-62). Furthermore, ethical dilemmas loomed large, particularly concerning privacy and copyright issues (Dobrick et al., 2018:91; Lomborg, 2012; Mutlu, 2015). The act of scraping, viewed critically in light of prevailing ethical guidelines (Krotov and Johnson, 2023) and discouraged by hosting platforms (Hernandez-Suarez et al., 2018), raised insurmountable questions about the responsible use of data. The ethical implications, coupled with the methodological misalignment and data noise, prompted a strategic pivot, redirecting the research toward more ethically sound and theoretically congruent avenues.

Following the abandonment of the experimental approach, a decisive shift was made towards adopting an archival methodology (Ferretti, 2020; Dwyer and Davies, 2010; Mills, 2013). This strategic transition was motivated by a dual objective: ensuring the reliability of data collection and analysis while laying the groundwork for future investigations. The archival approach not only offers a more robust and controlled means of gathering data but also aligns seamlessly with the theoretical framework guiding the project. In opting for archival methods, the intention is not only to fortify the current research but to create a foundation for analyses in the future. This methodological shift opens the door for potential collaboration with fellow researchers, transcending current limitations. By fostering inclusivity and collaboration, this methodology not only addresses the challenges encountered but also positions the project for sustained growth and contributions beyond the confines of its original scope.

Self-reflexivity and the positionality of the researcher stand as crucial considerations in qualitative research (Fisher, 2015). Positionality encompasses the deliberate choice a researcher makes regarding their stance within a given study, demanding an acute awareness of one's identity and its implications on the research.

Reflexivity, on the other hand, represents a continual process of questioning and challenging one's thoughts and beliefs. Extending from the project's inception to its dissemination, reflexivity involves acknowledging the researcher's impact on the investigation. This necessitates sensitivity to the dynamics of power in the research process and its influence on the researcher's relationship.

Self-reflection and a reflexive approach are not only prerequisites, but an ongoing necessity for researchers. This facilitates the identification, construction, critique, and articulation of their positionality. Contrary to the notion that social research operates in isolation from broader society and the researcher's biography, a reflexive approach advocates for acknowledging and disclosing the researcher's self in their work. Rather than attempting to eliminate personal influence, researchers should strive to comprehend subjective impact on and within the research process.

The cost of positionality lies in evaluating the advantages and drawbacks of self-identification in research methods. It involves disclosing how the researcher's racial, gender, class, or other self-identifications, experiences, and privileges shape their research.

Navigating the landscape of Anglo-Saxon academia, as an Italian woman from the working class, without prior formal education in the UK and with a background in Philosophy rather than in Social Sciences, posed challenges. The intersection of these identities created a complex tapestry that, at times, felt like an insurmountable barrier in what could be described as a challenging and, at times, hostile environment. The

challenges escalated to the point where seeking support became imperative. Initially engaging with the college psychologist and later with a private therapist, I received a diagnosis of CPTSD (Complex Post-Traumatic Stress Disorder). This revelation marked a turning point, propelling me to confront and address the mental health dimensions of my academic journey. A pivotal decision was the proactive change of the second supervisor, a move that proved to be helpful. With this adjustment, a more conducive supervision environment emerged, marking an improvement in the trajectory of my research, as results documented in the trimestral reports prove.

The already intricate canvas of my academic journey, painted with the challenges stemming from my background and personal struggles, underwent an unforeseen darkening with the advent of the COVID-19 pandemic. The global health crisis exacerbated the existing complexities, introducing unprecedented obstacles that reverberated throughout the academy. The transition to remote learning, isolation from the academic community, and the heightened uncertainties in an already demanding environment added layers of stress and difficulty (Leal Filho et al., 2021). The pandemic further underscored the resilience required to navigate academia.

Indeed, the COVID-19 pandemic has wielded a substantial impact on researchers, manifesting both methodologically and in terms of tangible effects on health. Methodologically, research projects have faced severe challenges, encountering difficulties in mitigating negative effects (Tremblay et al., 2021).

The tangible impact on health has been pronounced, with COVID-19 infections affecting both scientific members and participants. Research projects have borne negative repercussions, grappling with delays in data collection and analysis, along with

challenges in recruiting participants and conducting data collection (Rahman et al., 2021; Roberts et al., 2021).

The timing of my encounter with COVID-19 proved particularly challenging, coinciding precisely with the crucial phase of conducting data analysis. I found myself grappling with lingering side effects that manifested as both neuro-motorial and respiratory issues. However, the ordeal has reinforced my commitment to aiding future young academics who may find themselves navigating similarly challenging terrains. In the crucible of adversity, a deeper sense of purpose has emerged, propelling me towards a more resilient trajectory.

The onset of COVID-19 introduced an unexpected hurdle in my research journey, compelling me to maintain social distancing from my human participants. Initially, I perceived this situation as a great challenge, particularly given the complications cold contacts presented in the context of rigorous ethical procedures, as recounted above. However, with hindsight, I've come to appreciate the unanticipated advantages that social distancing afforded. Looking back at the Introduction, where I detailed instances of receiving peculiar or excessively emotional responses from interviewees, I find myself grateful for the buffer that social distancing provided.

The virtual space, while creating a unique set of obstacles, served as a protective layer, shielding me from potentially awkward or dangerously emotionally charged encounters.

Reflecting on these circumstances, it becomes a complex puzzle to untangle in consideration of which factor within my positionality played a more significant role in fostering such incidents[13].

The profound challenges stemming from my unique positionality have acted as catalysts propelling me deeper into a steadfast commitment to methodological rigor. As I navigate the intricacies of my identity within the academic landscape, grappling with complexities related to nationality, socio-economic background, and educational trajectory. Moreover, this journey has compelled me to consider what can be described as a reflective epistemology. Drawing inspiration from the *aesthetic of flotsam*, explored in the Introduction to this thesis, I embrace a deliberate commitment to instrumentalize this theory as a form of non-specialized philosophy (Garroni, 1982), fostering an epistemological approach that embraces self-reflection as its cornerstone.

3.10 Conclusion

In response to the call for new philosophies of digital mapping, this project situates Lidar imaging as a product of the evolution of driverless cars, positioning them as new media for the production of geographical knowledge within the digitalization of urban spaces. The intricate exploration of Lidar technology becomes imperative to discern the specific patterns of power and knowledge embedded within the sensor, unraveling both risks and

[13] Lastly, a somber acknowledgment is reserved for the distressing statistics surrounding suicides within British academia, a set of numbers that may not capture the full extent of the issue (Weale, 2022). The incomplete nature of these statistics is particularly poignant when considering those who, after resigning from their studies, may no longer be officially classified as students and therefore go unaccounted for in these records. Additionally, a solemn reflection extends to those who, in pursuit of their research questions, found themselves in perilous situations, to the point of death, with academic pressures and other contributing factors converging to create hazardous circumstances (De Guttry and Capone, 2017). This underscores the urgent need for comprehensive support structures within academia, addressing mental health concerns and mitigating the profound challenges that scholars may face on their academic journeys. The gravity of these situations calls for collective introspection and a concerted effort to foster a culture of well-being and understanding within academic institutions.

potentialities. As cities grapple with data governance processes, geographers have dissected the potentialities and risks associated with new data collection technologies. Private organizations' increasing involvement in policymaking has been likened to a metaphorical *trojan horse*, silently eroding urban public values. This metaphor extends to *technological opacity*, automated within normalized operations of data collection, sorting, and visualization, as observed during the evidence collection for this project.

In articulating the research aims, the thesis delineates three primary objectives: to chart, code, and decode the discourse reinforced by Lidar imaging; analyze the relationship between data collection and visual representations; and describe the spatialities and temporalities generated by Lidar imaging and its deployment. This endeavor aims to illuminate the articulation of power and knowledge inherent in Lidar, unraveling Cartesian residual conceptions and recognizing the consequences around aesthetic issues.

The methodology employed involves creating an archive of Lidar images extracted from companies' websites, shifting the research focus, because of practical obstacles, from knowledge communities and their digital labor to the empirical definition of the notion of epistemic tool and the meaning-dense geovisualities it produces. This approach involved studying more than 80 key companies' websites, capturing relevant images, and archiving them along with specific web addresses. The creation of this archive engages with conceptualizations of the archive. Content analysis and discourse analysis are applied to the archive, with the objective of charting Lidar's significance and code emerging themes within its visual rhetoric. Additional analyses explore videos from YouTube, and then hardware analysis, through white papers and blog posts, to scrutinize the materiality and mechanics of the Lidar sensor.

Despite facing exigencies like the COVID-19 crisis and personal health challenges, the project has successfully addressed its research questions. Lessons learned include the importance of self-reflexivity and adaptability, especially in navigating unforeseen circumstances. Looking ahead, the project suggests future paths for further development, advocating for the reiteration of analyses with different epistemologies and theoretical frameworks. Collaborations with researchers from other fields, possessing diverse identities and sets of skills, are also envisioned, with the objective of further enriching and expand the project's scope and its methodologies.

Chapter Four

Prominence and significance of Lidar imaging online

4.1 Introduction

The analytical core of this chapter is represented by an Internet survey of websites owned by companies involved in the supply chain for autonomy in the automotive sector. Each and every one of the businesses selected for the study is involved in the perceptive side of the making of the driverless car. Robotic perception, in this field, involves the fusion of data from different sensors to allow the formulation of the automated responses that the vehicle needs to navigate the environment safely (Hind, 2019). As a marketing strategy, most of the firms and start-ups inhabiting this financial and technological landscape deploy visual tools to build an image as cutting-edge technology leaders, thus attracting investors and high-level partnerships. These images are nonetheless incredibly hard to define; they betray the tradition of cartography and digital mapping in more than one way. The first betrayal is in the place of their production: they are the result of renderings outputted from proprietary software that has a lot more to do with engineering than usual digital mapping (Tyner, 2020). Secondly, these images, sometimes called 3D maps or HD maps, have completely abandoned the typical format of traditional, both digital and analogical, bidimensional maps, being natively designed to model an environment (Ebrahimi Soorchaei et al., 2022). Moreover, they are typically displayed as part of complex marketing strategies by specific brands: instrumentally deployed to sell an idea, tied to a product or service, inscribed within a brand identity.

The present chapter aims, in the first instance, to establish an archive (Thylstrup et al., 2021) of Lidar imaging as it appears on companies' websites. As online pages are often updated to better represent current companies' missions and goals, the desire is to provide a slice of time within the ephemeral emergence of disappearing images produced by Lidar sensors. Secondly, content analysis of the images included will jump-start the process of charting the deployment of Lidar imaging. This first close contact with the images included in the archive will open up the route towards probing, from multiple angles, the

discourse circularly produced and reproduced by and from Lidar imaging in the following chapters. The final goal of the whole thesis is to reverse engineer how data is collected and organized through Lidar sensing and what kinds of representations of space and time are generated to manage space. This process of back-engineering has been designed to circumnavigate secrecy and black-boxing (Christin, 2020; Latour, 1999), but in turn offers the advantage of tackling the production of representations of space holistically by considering how software and hardware architecture integrate for the generation of data visualizations of the environment. I turned towards Lidar companies involved in the making of the driverless car as they are positioned in the context of the datafication of urban life (Bibri, 2019) while acting as a form of new media (Huhtamo, 2020) that produces representations of space. Lidar imaging, sitting materially at the intersection of fiber optics as the nervous system of telecommunications (Warf, 2017) and advancements in robotics and perception, and culturally within narratives of data governance, offers a vantage point towards a critical understanding of how new modalities of space management, with their rich entanglement of knowledge and power relations, are being produced.

Given the fuzzy boundaries of the object of analysis, a careful definition of the elements involved is necessary. Therefore, the chapter will be divided into parts as follows: in the first part, Lidar imaging will be defined as an object of interest for critical cartography, positing different kinds of geographical imaging that can momentarily help in better understanding its hybrid positioning. The definition that best describes Lidar imaging is the notion of "geovisuality" as it is advanced by geographer Dodge (2018).

After this provisional definition, Lidar geovisualities will be framed as the latest incarnation in the long tradition of geographical imaging serving persuasive purposes, according to the categorization offered by geographer Tyner (1982; 2020). This framing

will be subsequently complicated by an account of questions posed by Google Street View, as it has been posited as one of the first instances of augmented mapping (Hoelzl and Marie, 2014; Gilge, 2016).

In the third part, the Internet survey at the core of the study will be presented. The results, stemming from the content analysis of eighty companies involved in the production of Lidar imaging, shown in Table 1, will be orderly considered according to the analytical categories used during the analysis (presence and prominence, scale, animation, interactivity, date of data extraction).

A complete set of the different images collected from the survey is provided in Appendix A. This analysis wants to preliminarily clarify the status of Lidar imaging, considering especially its relevance in branding and then its meaning at large. After that, conclusions stemming from the results of the survey will be weighed to further develop the analysis in the next chapters and shed light on the entanglement of knowledge and power within the production of Lidar imaging.

4.2 Defining Lidar imaging

It's hard to look at a point cloud and see a map in it. Numerous and variously distanced speckles of neon color dance on a black background, tracing the shapes of everyday landscapes and the objects that populate them. The rendering coming out of a Lidar sensor (even when fused with other sensors to surpass its own technical limits) can at most resemble a ghostly VR simulation of reality instead of a map. And arguably, this imagery dishevels the semiotic triangle between territory, place, and its representation, as it has dominated the history of cartography since the Mercator projection of the globe on a flat sheet of paper (Duarte, 2017). Nonetheless, verticality (Elden, 2013), brought in the form of satellites and drones, especially (Crampton, 2016), as well as different geometries of

space brought forth also through Google Street View and its cars (Elwood and Leszczynski, 2013), is here to stay, stretching the edges of what can be considered a map and revealing new vantage points in the apprehension and representation of the environment.

New mediated forms of cartography are becoming more and more pervasive, not only through so-called "data journalism", but also in pedagogical contexts and through apps providing geolocation services. In the words of geographer Martin Dodge:

> The notion of mediated geovisualities is a useful way to think about contemporary applied cartography and geoweb services that are extending what a "map" can be. Geovisualities situate mapping as a practice at the intersection of social and cultural concerns, along with attention to visual aesthetics and the underlying spatial data, geocoded imagery, and algorithms of GIS science. (2018:956)

In this paper, the geographer Martin Dodge makes a direct link to how 3D mapping, among other kinds of representation, is extending the notion of the map while not completely substituting it in the foreseeable future, especially with the rise of high-resolution satellite imagery and sensor data through drones. The perils of the "view from nowhere" (Valentine, 2016; Kurgan, 2017; Weizman, 2017), along with the ethical problems posed by such technology stemming from the army, are also remembered (Boucher, 2015). Moreover, specific attention is paid to place mapping at street level. The explanatory example here is provided by Google Street View, which, with the official launch of its service in 2007, allows exploration of almost the whole world without ever leaving the comfort of home. Once again, this innovation raised many concerns regarding the politics and ethics of the endeavor (Shapiro, 2018) and the modification in economic behavior (Alvarez León, 2016).

As of today, Google Street View services are routinely used in research (Langton and Steenbeek, 2017; Li et al., 2017; Naik et al., 2017) and criticized for the biases that might arise from such academic practices (Power et al., 2012). Moreover, as the state is retiring from the cartographic project, new mapping technologies are left in the hands of corporations, start-ups, and grassroot movements, all of which produce different effects on knowledge production and patterns of power.

On a first level, Google Street View's imaging of the environment poses questions in regard to the nature of the map. As noted by geographer Gilge (2016), Google Street View mapping is the hybrid product of diagramming the environment to garner and represent spatial information and of capturing spatio-temporal representation with photographs. This way of spatializing photography, connecting it to coordinates while providing services of navigation that impact mundane operations of wayfinding, establishes a visual archive of the world that has a fluid appearance but is fractured by layers of technologies and contested places. The layers of different technologies, which entail different points of view and therefore different geometries, are connected to the fact that, in the first place, Google Maps operations started with the acquisition of the satellite imagery company Keyhole back in 2004. In 2007, street-level operations started with the famous car, which posed many privacy concerns. As the project evolved, the cars were substituted with smaller and smaller capture devices that could easily fit in a backpack. The contested places that inhabit the fluid appearance of Google Street View are connected to the fact that different users could interact photographically with the platform, and the stitching of different captures is not always smooth, especially when comparing rural areas with urban areas. Moreover, an additional feature that makes Google Street View one of the richest visual and spatial experiences is the fact that the user can easily switch between map, satellite view, and exploration of the photographically captured environment. Gilge

highlights how the photographic archive of the world offers possibilities for exploration and creative use, granted by the fact that the experience of using Google Street View is not comparable to just looking at pictures; it entails moving through the image in a three-dimensional way that, through the hand-eye connection, retains some haptic qualities typical of real-life exploration.

Gilge's contribution, however, resides in finding a predecessor to Google Street View in the Aspen Movie Map Study at MIT (1978–1988). Described in detail by Mohl (1981), the experiment entailed filming the streets of a city in Colorado that would constitute the basis of a navigable 3D interface. The idea behind the experiment was to measure how users would learn how to navigate a space through maps and visual representation; such knowledge was considered necessary in military exercises. What's important to note here, beyond the positive conclusions of the study, is that both the map, with its Cartesian construction of the subject that controls the construction of territories and political communities through the spatial diagram (Cosgrove, 1985; Jay, 1988), as well as the photograph, which creates proximity between the viewing and capturing subject and the landscapes through the optical aperture of the camera (Pettersson, 2011), are intensified in three-dimensional experiences, as it creates ambiguous marks between experiencing and experiencing the image.

The ontological dilemmas unlocked by these new technologies are still hard to exactly define and foretell. While Gilge investigated such questions from a formal point of view, Hoelz and Marie's (2014) study penetrates the algorithmic operations behind the spatial-visual operation of Google Street View. By analyzing in detail the digital artifacts caused by the imposed necessity to ensure the anonymity of people accidentally captured by the Google camera, Elpel, the authors of the paper can make visible the usually invisible algorithmic operations of capturing and retrieving when the user requests the exploration

of a location. Pointing out how the coupling of geographical topography and photography can be traced back to war techniques with air balloons at the end of the XIX century, the authors note how such techniques were explicitly recognized as essential by Edward Steichen, Chief of the Photographic Section of the US Air Service during the First World War (Steichen, 1963). The authors then turn to literature concerned with cyberwarfare and define the images proposed by Google Street View as "operative images" (Farocki, 2004). This means, according to them, that these images are the product of making a dataset of the entire Earth, but, in so doing, the symbolic relationship between representation of space and environment is collapsed: the whole environment is a dataset that can be retrieved by algorithmic operations with different actors, human and non-human, entangled in the framework.

These two studies, trying to make sense of the horizontal and vertical, visual and spatial, perspectives afforded by Google Maps and Google Street View, are good precursors to understanding the problems posed by Lidar imaging as a tool to be integrated in the algorithmic processing of real-time data mined from the city, with the envisioned final aim of establishing fully autonomous navigation within the urban context.

Lidar imaging sits exactly in the middle between 3D imaging, the latest development in optical telecommunications, and the application of automation to the field of mobility. Lidar imaging as a geovisuality, nonetheless, is also challenging this very definition because, through its technology of projecting manipulated light on the surface of the surroundings, it does provide images that look like ghostly photographs but are, instead, visual representations of distances inscribed within space.

As of today, the sites where Lidar imaging has gained major screen placement are companies' websites commercializing their Lidar-based services, making Lidar

geovisualities the latest embodiment in a long tradition that sees geographical data and persuasion go hand in hand.

4.3 Persuasive Cartography

The power of maps and the capacity they hold to impose a singular point of view as objective through design choices is a foundational pillar of critical geography (Harley, 1992; Monmonier, 1996; Wood, 2010). This influencing force hinges upon its invisibility: an image holds the most power when the cutting out of its peculiar viewpoint as universal goes absolutely undetected.

As geographer Tyner has pointed out (1982; 2020), all maps carry within themselves both information and persuasion. All information contained within the graphic design of a map is the product of a process of selection of geographical knowledge as well as choices that condition the readability of the information within the limited physical space of the page or of the display. Moreover, all informational maps carry within themselves the desire to be seen as objective representations of truth, positing themselves within the confines of scientific imaging. Tracing the line between information and persuasion is one of the most difficult tasks when it comes to gatekeeping scientific methodology in geographical departments and journals.

Persuasion in mapmaking stands on a spectrum. Among persuasive maps, the most pernicious ones are certainly propaganda maps. These maps are the ones that are consciously designed to promote a partial political view. Notorious examples of this are the maps produced at times of war, often sustaining an overtly racist discourse (Muehlenhaus, 2012; 2013). On a more subtle level, it's once again a very well-known fact that the maps included in many world atlases encapsulate, through specific projection

choices, a form of Western ethnocentrism that appears to be dictated by geographic "natural" dispositions of the land (Castex, 1993). Propagandistic maps are also often used in counter-hegemonic attempts to sway politics away from state-led projects, for example, when it comes to nuclear power or climate change activism (Drozdz, 2020).

As noted above, with the retirement of the nation-state from the cartographic endeavor and the expansion of new means to produce cartographic objects (Cloud, 2002), the torch of persuasive mapping was taken on by private businesses for advertising (Francaviglia, 2005). Nonetheless, the deployment of cartography for marketing purposes hasn't been engaged in critical manners quite often. An example of persuasive cartography in advertising can be found, historically, in the maps designed to produce a mobility culture hinged upon a network of railroads, highways, urban metro lines, and airways.

Railroad cartography was born in the middle of the nineteenth century with the marketing of different companies building networks between North American cities. It was important to be able to translate in an efficient manner many different elements (like tickets' fares, timetables, and so on) to attract the highest number of travelers (Modelski, 1984; Musich, 2006). In the USA, another important evolution in the history of persuasive mapping was the one represented by route maps to promote the individual automotive market (Akerman, 2002). Once again, these maps had to represent in a captivating manner the grid of highways across the land, along with gas stations and different amenities. Another iconic example of persuasive mapping is most definitely the London Underground diagram (Garland, 1994), designed by Harry Beck. This map is notorious for the topological simplifications it depicts in order to sell an easy-to-read orientation tool for metro riders, as well as for portraying the image of an urban conglomeration that, at least on paper, has been freed from all its topographical convolutions. An even more recent and cogent example of this kind of cartography is offered by airline maps (Thurlow

and Jaworski, 2003), often printed in airlines' magazines and sometimes displayed on mini screens for all passengers, even offering a certain degree of interactivity. Once again, these representations offer at the same time information for clients while building a brand identity, connected to the idea of networking the whole world through airways. There is a long history, therefore, of maps being part of commercial advertising. When it comes to Lidar imaging, another interesting predecessor might be seen in telecommunications network maps (Dodge, 1997; Dodge and Kitchin, 2003; Jiang and Omerling 1997). At the dawn of the Millennium, representations of cyberspace, initiated in the 1960s with ARPANET topological modeling, became popular both for academics and for telecommunications networks. Once again, the objective was to make visible the invisible—either the infrastructure or the labyrinth of the net, or for the other examples: an idea or a simplified topology that allows easier mobility—while at the same time building an image of scientific transcendence and overpowering connection capabilities -- a phenomenon termed "cyberboosterism" (Dodge and Kitchin, 2000).

Lidar imaging comes once again into this established tradition to upset crystallized tendencies and established semiotic relationships. In its mode of appearance, as a direct reflection of spatial relationships within a given environment, Lidar imaging commands scientific objectivity for itself without leaving space for questioning. While every form of mapping requires a codified and symbolic translation between the territory and its rendition on the map, 3D mapping and modelling -- with the apparent direct correlation between data points and the site of their extraction -- makes invisible the mediating processes involved in the making of the final image. At the same time, paradoxically, these kinds of images make visible in a novel manner something that is already visible.

Moreover, Lidar geovisualities are also displayed on manufacturer websites to build an image for themselves, more than to sell a product, as their key audience is represented by

financial journalists and, more importantly, venture capitalists, investors, banks, and partners within the automotive supply chain. In order to grasp how these geovisualities function, I propose an internet survey that aims at establishing the prominence and provisional meaning of the presence of such visuals on websites. The next chapter, having established the critical geospatial reference of the analysis, will develop a more targeted and in-depth discourse analysis of what these images are meant to convey.

4.4 Internet Survey Results: Sample and Categories

To advance a critical appraisal of Lidar imaging within digital cartography, after having reviewed a set of genealogical tools, I propose an internet survey that aims to provisionally define the prominence and meaning of displaying Lidar outputs. In what follows, I'm going to quickly describe the chosen sample, as well as the charted categories, before describing the results of the survey.

The categories outlined in the Table, guiding the content analysis of the eighty companies, have been meticulously chosen to align with the primary objective of this chapter. The central aim is to assess how Lidar imaging, functioning as a geovisuality, can be evaluated within the framework that defines map-making as a scientific form of image production (Tyner, 2014). In essence, maps can be perceived as a manifestation of scientific imaging due to their capacity to visually represent spatial data. Characteristics that define a map as a form of scientific imaging include, but are not restricted to, spatial, spectral, radiometric, and temporal resolution, projection methods, and the utilization of symbols and legends.

Historically, cartographers have played a central role in mapmaking, engaging in tasks such as gathering, interpreting, and visually representing geographic data. Their responsibility lies in the design and creation of maps that represent spatial data and

effectively communicate geographic information to diverse audiences, according to an established set of criteria. However, the advent of technology has significantly impacted the field of cartography, revolutionizing the processes of data gathering and then map creation, utilization, and dissemination.

Digital mapping, GIS, remote sensing, mobile mapping, and 3D mapping are among the technological advancements that have reshaped cartography. Consequently, cartographers now face new challenges, including keeping pace with technological advancements, maintaining accuracy, balancing automation and creativity, ensuring accessibility, and addressing ethical concerns. Cartographers must remain cognizant of these challenges, taking proactive steps to guarantee the accuracy, accessibility, and ethical integrity of their maps.

Remote sensing and mobile mapping have introduced new perspectives to the field, attracting individuals from diverse backgrounds, such as archaeology, physics, or engineering. As Dodge succinctly highlights in the quote above, geovisualities broaden the horizons of geography, providing a visual representation of geographical data that intertwines with various interdisciplinary factors.

With the aim of contributing to the critical understanding of geovisualities, particularly those produced by Lidar, this analysis begins by cataloging the appearances of such images on producers' websites. The initial evidence essential for this analysis lies in the mere presence or absence of the image. Subsequently, it is crucial to consider the prominence given to the presence of the image, providing tangible insights into the mode of its presentation. In alignment with Tyner's spectrum, the survey seeks to determine the level of retained information contrasted with the persuasive power infused into the image

through its presentation modality. This involves considering the presence or absence of markers traditionally used to assess the scientificity of a geographical representation, including the time and place of data extraction, scale of representation and modes of presentation.

Dodge notes that geovisualities have become a significant trend in Web 2.0, where interactivity is viewed as a valuable means to visualize and explore data in novel ways. Consequently, the category of interactivity has been incorporated into the analysis, along with the examination of the presence of animated images, a topic to be explored in detail in Chapter Six.

Table 1: deployment of lidar imaging on the websites of eighty lidar-based companies, April 2022 (Source: Author survey. There is no official way to rank start-ups as the ranking can depend on various criteria, such as market capitalization, revenue growth, user base, funding, social impact; Makai, 2021)

				Scale						
	Corporation (location)	Website	GV	Room	Street	City	Regional	Interactivity	Date	Animati
1	Aeva (USA)	https://www.aeva.com								
2	Aeye (USA)	https://www.aeye.ai								
3	Aimotive (Hungary)	https://aimotive.com/aidata								
4	Ams (Austria)	https://ams.com/en/ams-start								
5	Aptiv (Ireland)	https://www.aptiv.com								
6	Argo.ai (USA)	https://www.argo.ai								
7	Aurora (USA)	https://aurora.tech								
8	Baraja (Australia)	https://www.baraja.com/en								
9	Here (Netherlands)	https://www.here.com/solutions/infrastructure-planning/bentley								
10	Blackmore									
11	Cepton (USA)	https://www.cepton.com								
12	Cruise (USA)	https://www.getcruise.com								
13	Daimler									
14	Dataspeed Inc. (USA)	https://www.dataspeedinc.com								
15	Deep Map									
16	Delta Lidar (Turkey)	https://www.deltalidar.com								
17	Draper (USA)	https://www.draper.com								
18	Espros (Switzerland)	https://www.espros.com/								
19	Fastree-3d (Switzerland)	https://fastree3d.com/								
20	Ficontec (Germany)	https://www.ficontec.com/								
21	Geosun (China)	https://www.geosunlidar.com/								
22	Hesai (China)	https://www.hesaitech.com/en/								
23	Ibeo (Germany)	https://www.ibeo-as.com/en								
24	II-VI (USA)	https://ii-vi.com/								
25	Nuro (USA)	https://www.nuro.ai/technology								
26	Innovitz (Israel)	https://innoviz.tech/								
27	Innovusion (USA)	https://www.innovusion.com/								
28	Kodiak (USA)	https://kodiak.ai/								
29	Kyocera SLD Laser (USA)	https://www.kyocera-sldlaser.com/								

30	Labsphere (USA)	https://www.labsphere.com/									
31	Leddar Tech (Canada)	https://leddartech.com/									
32	Leo Drive Ai (Turkey)	https://leodrive.ai/									
33	Leonardo electronics (USA)	https://www.leonardo.us/									
34	Lumentum (USA)	https://www.lumentum.com/en									
35	Luminar Technologies (USA)	https://www.luminartech.com/									
36	Lumotive (USA)	https://www.lumotive.com/									
37	Lyft autonomous (USA)	https://autonomous.lyft.com/									
38	Mobileye (Israel)	https://www.mobileye.com/									
39	Navya (France)	https://navya.tech/en/									
40	Nvidia Drive (USA)	https://developer.nvidia.com/drive									
41	Omni Vision (USA)	https://www.ovt.com/									
42	Onsemi (USA)	https://www.onsemi.com/									
43	Opsys (Israel)	https://www.opsys-tech.com/									
44	Orbit (Belgium)	https://orbitgt.com/									
45	Ouster (USA)	https://ouster.com/									
46	Oxbotica (UK)	https://www.oxbotica.com/									
47	Oyla (USA)	https://oyla.ai/									
48	Phoenix Lidar (USA)	https://www.phoenixlidar.com/									
49	Pony Ai (USA)	https://pony.ai/									
50	Preact (USA)	https://www.preact-tech.com/									
51	Princeton Lightwave										
52	Quanergy (USA)	https://quanergy.com/									
53	Robosense (China)	https://www.robosense.ai/en									
54	Sense Photonics (USA)										
55	Sensible 4 (Finland)	https://sensible4.fi/									
56	Strobe										
57	TetraVue (USA)	https://sensible4.fi/technology/									
58	Trilumina										
59	Tusimple (USA)	https://www.tusimple.com/									
60	Understand.ai (Germany)	https://understand.ai/									

61	Valeo (France)	https://www.valeo.com/en/									
62	Velodyne (USA)	https://velodynelidar.com/									
63	Vislab (Italy)	https://vislab.it/									
64	Visteon Corporation (USA)	https://www.visteon.com/									
65	Waymo (USA)	https://waymo.com/									
66	Xaos Motors (China)	https://sensor.xaos.ai/									
67	Xenomatix (Belgium)	https://xenomatix.com/									
68	Xilinx (USA)	https://www.xilinx.com/									
69	Yandex (Russia)	https://sdg.yandex.com/									
70	Zoox (USA)	https://zoox.com/									
71	Ydlidar (China)	https://www.ydlidar.com/									
72	Ocular Robotiscs (Australia)	https://www.ocularrobotics.com/									
73	Veoneer (Sweden)	https://www.veoneer.com/									
74	Torc obotics (USA)	https://torc.ai/									
76	Prophesee.ai (France)	https://www.prophesee.ai/									
76	Outsight (Finland)	https://www.outsight.ai/									
77	Dspace (Germany)	https://www.dspace.com/en/ltd/home.cfm									
78	Hamamatsu (Japan)	https://www.hamamatsu.com/eu/en.html									
79	Microvision Inc. (Germany)	https://www.microvision.com/									
80	Blickfeld (Germany)	https://www.blickfeld.com/									

10. Blackmore: acquired by Aurora
13. Daimler: absorbed by Mercedes-Benz
15. Deepmap: acquired by NVIDIA
51. Princeton Lightwave: acquired by Argo.ai
54. Sense Photonics: acquired by Ouster
56. Strobe: acquired by GM Cruise
58. Trilumina: acquired by Lumentum
66. Xaos Motors: website currently down

GV= geovisualities

Legend:	
GV in homepage	
GV in secondary page	
GV ancillary pages	
GV found through search	
GV not visible	

4.5 Website survey results: Lidar imaging presence and relevance

The survey discovered the presence of Lidar imaging on fifty out of the eighty companies' websites inspected (seventy-two point five percent). This first result from the survey, based upon the simple presence or absence of such images, shows how representations of the environment through Lidar sensors, with their typical aesthetic features, are broadly deployed by firms.

Looking at the results by themselves, it's impossible to determine what specific reason might convince a company to deploy or not this very specific kind of imagery, although it's important to note that the eight companies with the biggest net worth are all showing some form of Lidar imaging. The connotative meaning inscribed in such images will be analyzed in the next chapter. Considering competitiveness among the firms and the level of industrial secrecy around every step of the autonomy supply chain, but especially with attention to the software necessary to interpret the amount of data flowing from sensors, two things must be noted. The first one represents a cautionary note: it's impossible to determine with certainty from the visual analysis of such images if the ones displayed are the ones produced by sensors and deployed on a technical level. The second one, stemming from such a premise, is that the biggest businesses go through a lot of effort to present a form of visual that enhances a scientific look to sustain the prominence of their activities in the tech niche. Given the previous form of uncertainty around the intentionality surrounding the exhibition online of such geovisualities, it can only be assumed as a provisional working hypothesis that the commercial goal is to aid in the construction of the image of the company, positioning it in the unstable market as reliable providers of up-to-date and cutting-edge technology.

It's also important to add that only images representing the typical Lidar rendering were included in the analysis (keeping in mind the caveats illustrated above). This means that other companies employing different types of 3D visualizations were charted but not

included in the categorization reflecting the use of Lidar imaging. The ample spectrum of commercial imaging produced for advertising driverless cars includes 3D renditions of vehicles and cities through different media, like video or GIFs, fragments or screenshots from simulations, and visual animation illustrating the elements composing the perceiving system of the car and how it works. These types of commercial images, which are not directly Lidar-based but still deploy the 3D representation of space, will be touched upon in a later paragraph in this chapter.

Other marketing strategies heavily deploy topological diagrams to illustrate the functioning of the technology being sold (Siricharoen, 2013), but they will not be included in this analysis nor discussed in their meaning.

The website survey evaluated Lidar imaging prominence on the companies' pages and, inferentially, the weight associated with them in marketing terms, thus going beyond the mere registration of presence or absence. The accessibility of the content and its position within the hierarchy of website pages were used to measure its prominence. The use of such imaging by the various firms was then coded into five categories:

1. Lidar imaging is prominently displayed, shown on, or linked and embedded on the homepage;
2. Lidar imaging shown on secondary pages;
3. Lidar imaging shown on ancillary pages;
4. Lidar imaging is only accessible through keyword searches;
5. Lidar imaging is not readily visible on the company's website.

These categories correspond to specific colors used in Table 1. For example, companies that prominently display Lidar imaging on their homepage, are matched with the darkest shade of blue, while those that show it on secondary pages are represented by fainter

shades of blue. By referencing the legend provided with Table 1, readers can identify which category each company falls into based on the color coding used in the table.

A clear indication that these businesses view Lidar imaging as a distinguished tool for marketing their products and applications to potential clients and investors is the most prominent and visible category, which includes such images on the homepage of their sites. The limited space on the screen of the homepage demands that only the most important content be displayed there.

According to the survey's findings, out of the fifty businesses that presented a marketing strategy deploying Lidar imaging, 36 percent of them gave it great prominence by putting such visuals directly on the homepage. Usually, the eighteen companies deploying Lidar imaging on their homepage provide what looks to be a manipulated screenshot, usually taken from a demonstrative video showing how the sensors "see" space. Such videos are often linked in their full length on subsidiary pages.

This strategy is best illustrated by looking at the homepage of Baraja (see Figure 3), one of the most profitable companies from those sampled, with one of those epic tech stories (Mills and Pawson, 2012; Morente and Ferràs, 2018) that attracts investors and general praise (Marshal and Adamic, 2010): it started in a garage near Sydney and is now worth 300 million dollars.

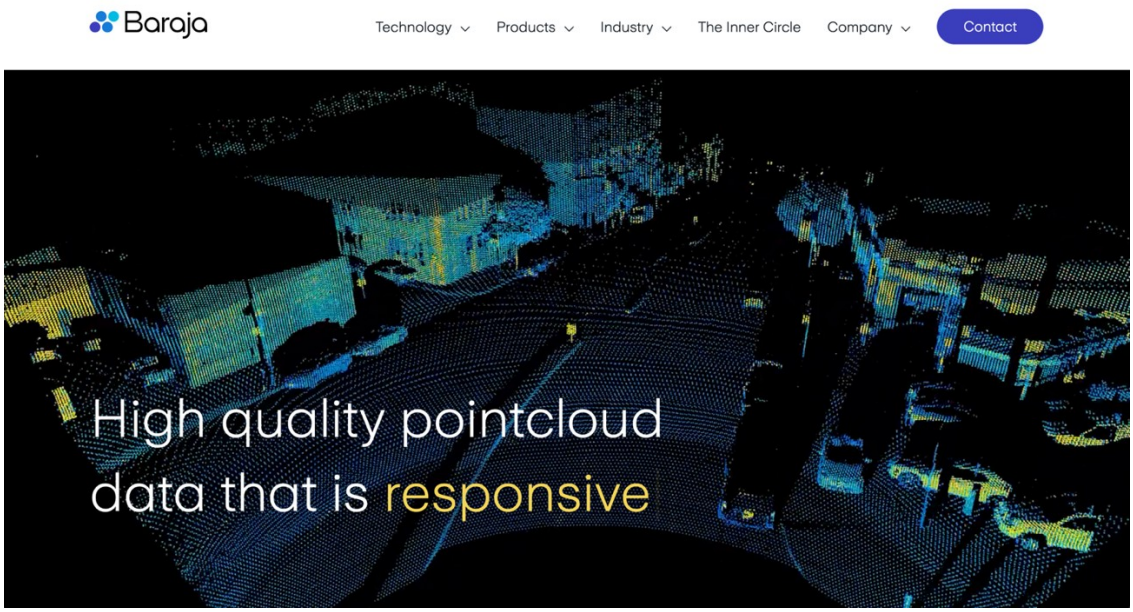


Figure 3 Screenshot taken from Baraja's homepage https://www.baraja.com/en last accessed 11/5/22.

The marketing strategy of Baraja devolves most of the screen space available on the homepage to various extracts from a video available in full length in a blog space that has been termed "Inner Circle". Among the entries available through the articles explaining in greater detail the strengths of the firm, there is one describing at length the technical solutions implemented to avoid point-cloud blurring.

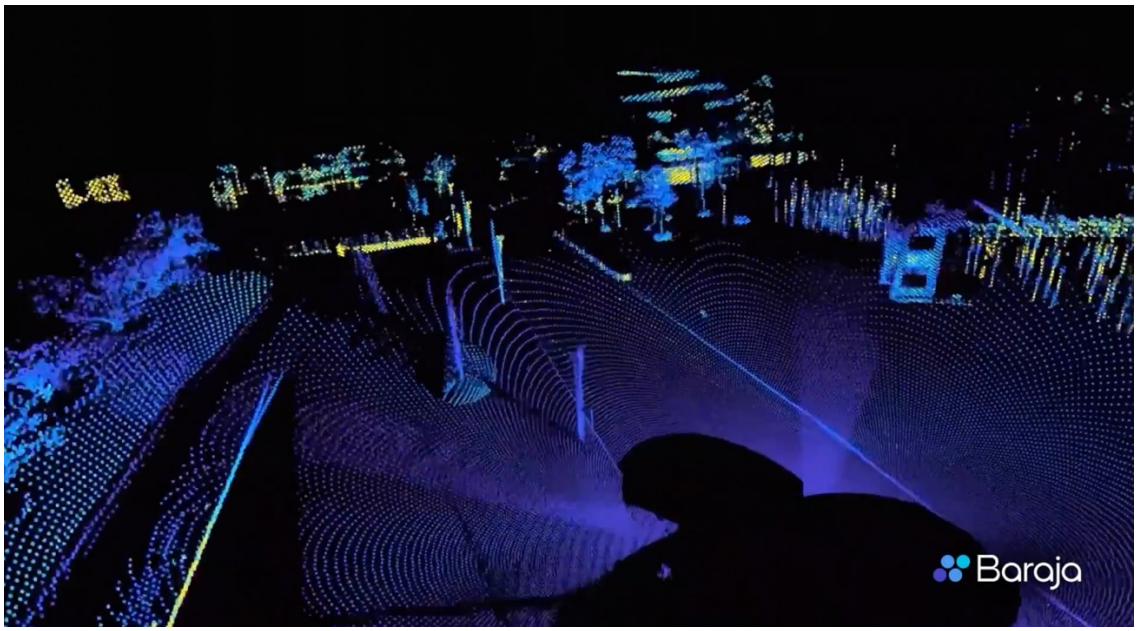


Figure 4 Screenshot of a demonstrative video taken from Baraja https://www.baraja.com/en/media last accessed 11/5/22.

These two images, the one taken from the demonstrative video (Figure 4) and the one taken from the homepage (Figure 3), demonstrate the technological kinship between them. Nonetheless, it's impossible not to notice the subtle aesthetic improvements present in Figure 4, made up for the most part by an adjustment in the contrast of colors and sharpness, to aid immediate readability for the viewer.

Among the eighteen companies deploying this kind of image on the homepage, prominently featured were the eight so-called "lunicorns", a neologism coined in financial dialect to indicate the Lidar-based startups that managed to surpass the threshold of one billion net worth, an accomplishment that shall promise them a longer life in the ever-changing landscape composed of emerging and failing entrepreneurial endeavors and that will be further analyzed in the next chapters.

The relevance granted to Lidar representations of space through their location on the websites underscores the perceived importance of such visual depictions of space, potentially serving as a means for these companies to position themselves as leaders in the field of autonomous driving technology. However, it is difficult to ascertain the extent to which marketing strategies influence this decision, or the specific goals driving the selection of visuals for display on these virtual platforms. Indeed, it is not within the scopes of this survey to establish casual relationships between the presentation of Lidar imaging and its financial effectiveness. As noted earlier, uncertainties surround the intentions underlaying the deployment of such geographical images on websites.

However, it's important to note that the choice of exhibiting Lidar outputs on the home page is not the sole prerogative of the most successful companies. Even less emblazoned businesses chose this kind of display to gather the attention of the viewer.

Over 38% of the companies having some form of Lidar imaging fell into the second class of relevance, with images prominently displayed on pages just one click away from the homepage (nineteen out of fifty-one websites surveyed). Usually, these firms prefer to focus the building of their commercial identity around a different kind of visual presentation, either shifting the focus towards the automated car or the benefits in the life of the final user of the vehicle. The pages devoted to a thorough description of the product offered—and how it is innovative and how the technology proposed works in simpler terms—generally host an embedded video with a demonstration. In some cases, the videos show a screen where software is being operated (sometimes including or not including the coding work necessary for the correct functioning of the tasks). Other times the protagonist is a human operating a computer, with the screen of their device in full view and the operating software showing lines of code scrolling through as well as point clouds of the environment being surveyed (see Figure 5).



Figure 5 Screenshot taken from a demonstrative video of Navya https://www.navya.tech/en/technology/software/ last accessed 22/1/2021.

It can be inferred, in these instances, that Lidar representations of space are thought to be useful for marketing but may not be deemed significant enough in the overall strategy to occupy the limited homepage space.

The third group of business websites included those whose Lidar imaging was present but not prominently displayed. This means that the manual search required several minutes of browsing and more than two clicks away from the homepage.

Seven out of the fifty organizations were in this category, or fourteen percent of all the start-ups, and they included, surprisingly, well-known North American firms like Aurora and Zoox (see Figure 6 and 7).

Both of these companies present excellent demonstrative videos, although they are quite

hidden away in the website hierarchy; therefore, deploying Lidar imaging was not at the forefront of their brand identity at the time of the survey.

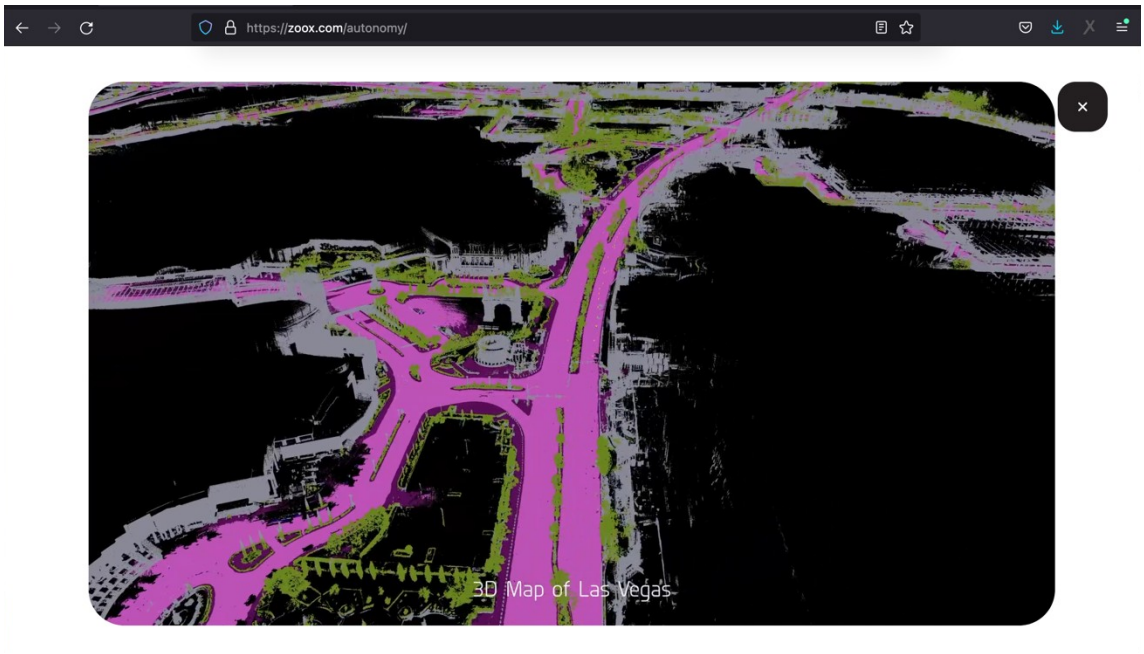


Figure 6 Screenshot taken from a webpage of the company Zoox https://zoox.com/autonomy last accessed 12/5/22.

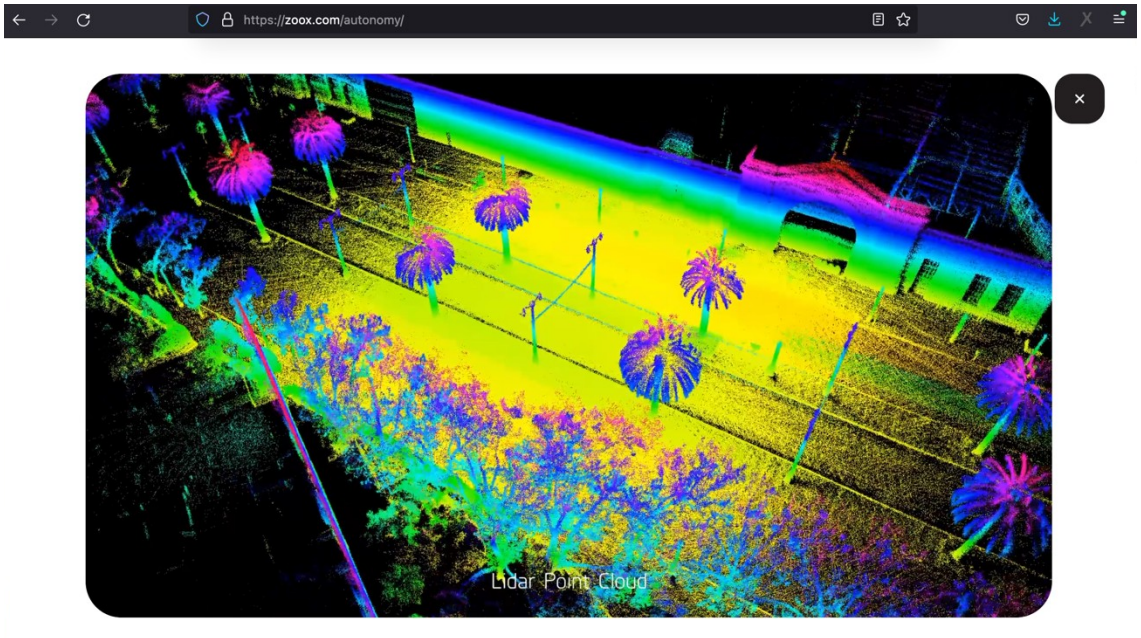


Figure 7 Screenshot taken from a webpage of the company Zoox https://zoox.com/autonomy last accessed 12/5/22.

The businesses' websites in the fourth category — which can only be found by specifically searching for the term "lidar" either using a specific bar embedded in the

website or sometimes using Google's Advanced Search tool — essentially conceal their scientific imaging. Six of the fifty websites displaying Lidar imaging showed this form of concealment. This number can be explained by the fact that most of the companies in this category are either chip manufacturers or focused on automation for industrial applications, so this might be the reason why Lidar imaging might not be seen as an essential part in the building of their brand image. Nonetheless, it was surprising to find it in this class. Here is the mapping division of Bentley, which historically specialized in HD mapping.

The final category includes all the firms that did not present any form of scientific imaging in the form of Lidar representations of space. The businesses included here were either chip manufacturers or laser and photonics firms, preferring to show photographs of their products or parts of them. Are also present in this category automotive companies choosing different forms of visual imaging (like 3D rendering, cinematic or animated videos, and simulations).

4.6 Website survey results: Lidar imaging and geo/time localization

In the above section, I have established that fifty out of the eighty companies considered in the survey chose to deploy Lidar imaging as a form of branding behavior. Having considered the prominence of Lidar imaging within the screen space of companies' websites, other pertinent contextual data was considered to further develop an understanding of the nature of such visuals and their deployment. These data are accounted for in table 1, under the categories of *scale, date, interactivity* and *animation*. In the next paragraph, I will explain why scale and date were taken into consideration, in order to highlight a swerve between displayed Lidar images and other forms of digital mapping. As advanced in the introduction, this is a necessary step to shed light upon what

I've called the "betrayal" of Lidar imaging towards both digital and analogical cartography. After that, I will briefly explain the category of interactivity, whereas animation will be briefly touched upon in the rest of this chapter, to be further analyzed in Chapter Six of this dissertation.

Since they employ a range of scientific methods—among which Lidar, as a remote sensing technology, is always enlisted—to convey spatial data in a visual manner, digital maps may be seen as instances of scientific imaging. To create an accurate map, the data collected needs to be precisely tied to the time and location of extraction, with the aim of providing a precise representation of geographical features (Kraak and Ormeling, 2010; Longley et al., 2015; Wilson, 2014). Therefore, the presence or absence of a specific date and localization pertaining to the images displayed, the scale of representation, and the availability of interactive features – as they can allow for data exploration - were all noted, with the aim of establishing the level of accurate information inscribed in such images. As it will emerge from the analysis of the survey results, Lidar imaging is deployed in a manner that unhinges the spectrum of information and persuasion, as it has been established by Tyner.

In the first place, only one of the companies included in the survey presented a video with Lidar imaging showing the exact location of data extraction and the time of the surveying operation (see Figure 8 and 9).

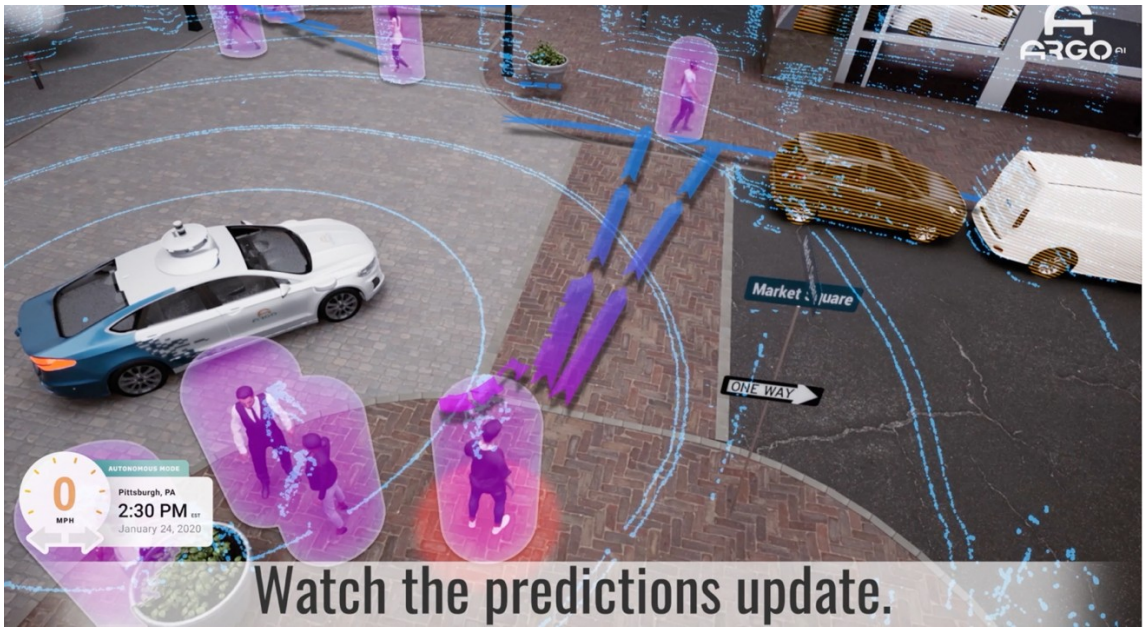


Figure 8 Screenshot taken from demonstrative video Argo.ai https://argo.ai/technology. Last accessed 7 May 2022.



Figure 9 Screenshot taken from the same demonstrative video from Argo.ai, a few seconds later. Last accessed 7 May 2022.

These stills are from a demonstration video from the North American company Argo.AI. This video presents an interesting mixture of storytelling. The subtitles accompanying the images explain how the company's software is better than the competition at recognizing objects in the environment and predicting their behavior and trajectory. On the screen, in the first image, a bird's eye view shows the sensing car proceeding in the street; the

concentric circles represent sensors collecting data. Different objects (cars, pedestrians, street signals, and architecture) are shown to be wrapped in different boxes; this should represent how the "brain" of the car is "segmenting" the scene, which means recognizing the elements and their trajectory and predicting where they will be in the following instants. The second screenshot shows, suddenly, a different point of view: the camera is vertical to the street, as if the city were being perceived through the eye of a satellite or a drone. Here, once again, a strange mixture between simulation and point cloud is presented, while a small rectangle in the left corner of the screen presents the regular camera point of view from the car. It's incredibly hard to establish what this video is really showing, given the mixture of 3D simulation, a bidimensional camera, and what appears to be a faint trace of a point cloud. Nonetheless, this is the only example in the whole dataset of visuals presenting a precise location and a precise time.

What can be deduced from this is that, in the framework of constructing a brand identity in the Lidar market, geolocalization marks and timeframes, which are the hinging sites in the production of geographical images as a form of scientific imaging, are not considered of high importance by the companies in their visual communications. The Lidar imaging displayed, therefore, taking into account all the cautionary notes already mentioned, is not showcased to build and sustain an identity that has its foundational basis in showcasing the accuracy of data extracted as conventionally established in cartographic practice. It should be noted that, for Lidar to work properly within the resolution of technical problems connected with the development of driverless cars in the urban landscape, the timing of data mining is deemed unimportant, as the georeferencing database undergoes continuous updates driven by the influx of incoming data. This is a strong suit of Lidar imaging, that supersedes cartography and the problem of updating datasets for accurate visualization. However, Lidar geovisualities displayed by companies on their websites

often lack essential temporal and spatial context. These visuals typically offer a static snapshot of the data at a specific moment, without indicating where and when the map of the environment was captured. This lack of time and place references diminishes their informative value, as viewers are unable to discern crucial details about the data. Consequently, these visuals tend to rely more on rhetorical appeal than on providing comprehensive information, aligning with the Tyner's categorization of persuasion presented in the dedicated section.

The images, with their typical, although minimally varied, neon and cyberpunk aesthetics, are presented only as a contribution to the overall "look", or "feel", of the tech start-up. An argument for the popularity of data visualizations has been made for their capacity to elicit emotional responses in the viewer (Kennedy and Hill, 2018; Kostelnick, 2016). Studies have shown how colors can affect the engagement of the final user with visualization in general (Bartram et al., 2017) and with maps in particular (Anderson and Robinson, 2022). But, considering how such images are presented, often as animated GIFs extrapolated from demonstration videos and retouched to improve their readability or enhance their appearance, Lidar imaging seems to occupy screen space because of its own "auratic presence". The concept of aura, when dealing with images, was originally formulated by Walter Benjamin in the essay "The Work of Art in the Age of its Mechanical Reproduction" (1936) to highlight how the original work of art had a form of undefinable authentic quality that inevitably deteriorated through copying. Nonetheless, in the original formulation, reproduction still opened up generative possibilities. However, in recent years, several scholars have argued that digital reproductions do possess a form of aura. Latour and Lowe (2020) argued for a migration of the aura in digital reproduction, while Kenderdine and Yep (2019), elaborating on this idea, noted a proliferation of auratic effects in algorithmic augmented images. Boyer (1996) engages in

a novel manner with Benjamin's thought, situating it in the cultural nexus created by the projection of the figure of the computer matrix on the urban landscape and productively connecting it with sci-fi and cyberpunk images and imaginary, shedding light on their power in reshaping the game of perception for the citizen. Comparing these ideas with Goldman and Papsons' (2011) study on the "cartographic fetish" exhibited by corporate brands in advertising to connect to an almost militaristic aura suggesting a globalist market expansion, it can be concluded that, in the context of this survey, it appears that Lidar imaging is deployed so as to command an idea of the ability of the firm to lead cutting-edge developments in the autonomy area, all the while creating an atmosphere of an already present future, disrupting the status quo.

When it comes to scale, the dataset of the survey presents only three categories:

1. room level;
2. street level;
3. and regional level.

Given the nature of the industry under scrutiny, it seems obvious that the vast majority of the sampled companies focused their attention on the street level to showcase the prowess of their hardware and software in capturing the street environment, rendering it into a point cloud that can allow the car to take decisions when confronted with different occurrences. Forty-one out of the eighty companies under scrutiny (fifty-one percent) presented various forms and different media presentations of some type of rendering of a street or a site of interest, like a bridge or a characteristic view, in a particular city (only Baraja, AEye, and Luminar specified the places they scanned).

Interestingly, three companies decided to display point cloud renderings of interiors:

rooms with people and different objects inside of them. Ams, a company dealing with artificial sensing for different industrial applications based in Austria, had a quite hidden demonstrative video with a man showcasing different Lidar applications for their sensor in the niche of automation while driving a fake wheel in a room equipped with computers, screens, and sensors (see Figure 10).

Tetravue, an American company producing Lidar cameras, had on its homepage a demonstrative video dated 2019 presenting the Lidar scanning of a room with a man, a child, and a dog, moving through a room decorated with street-like ornaments (see Figure 11).

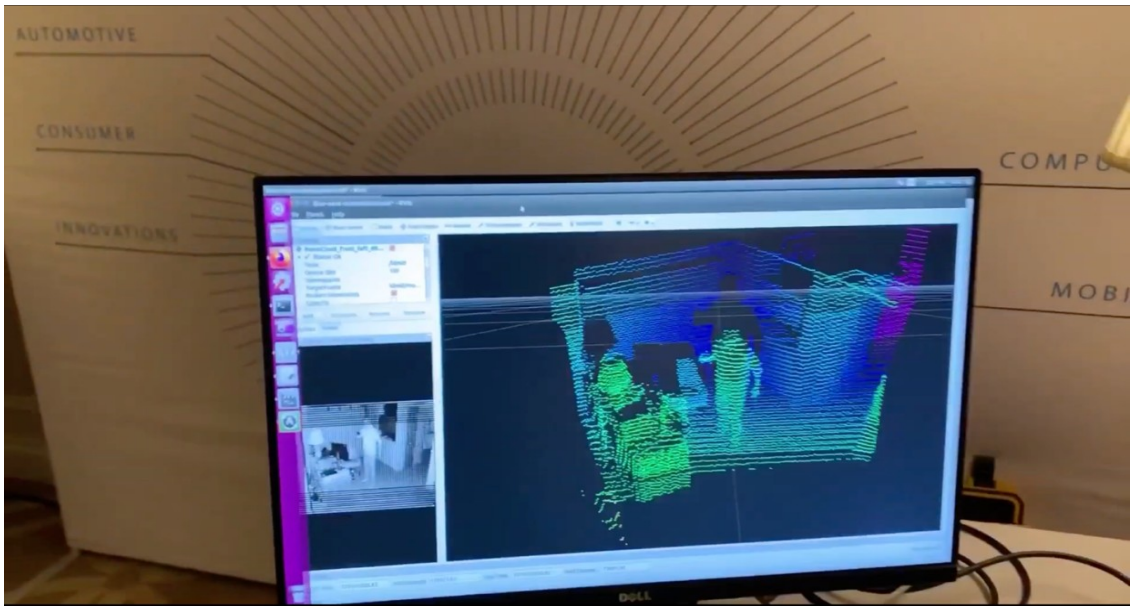


Figure 10 Screenshot taken from Ams' website https://ams.com/en/technology last accessed 29/4/22.



Figure 11 Screenshot taken a video embedded in Tetravue's website https://tetravue.webflow.io/videos last accessed 14/5/22.

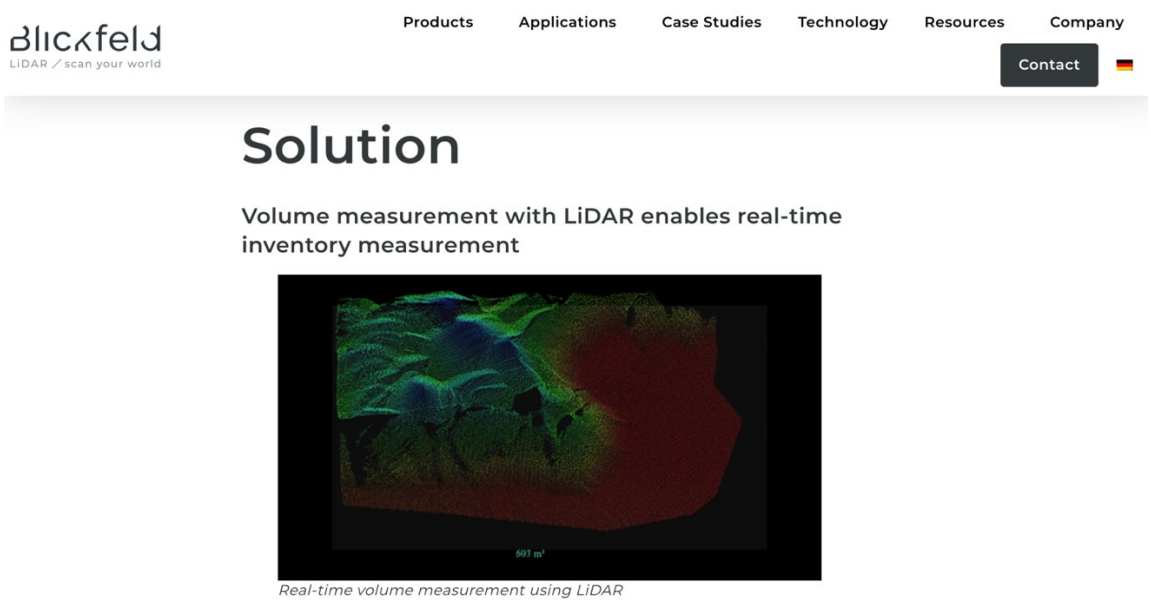


Figure 12 Screenshot taken from Blickfeld's website https://www.blickfeld.com/applications/volume-monitoring/ last accessed 4/6/22.

Blickfeld, a German firm selling Lidar hardware for different applications, presented on a subsidiary page a still point cloud from the interior of a warehouse, demonstrating a less

popular deployment of the technology (see Figure 12).

When it comes to the regional scale, there is a bit of overlapping, as some of the companies presenting their efforts at street level, in certain cases, also presented visuals on an ampler scale. Nonetheless, it is worth noting that the firms devolving more screen space to the ample regions they can cover, be it in an urban setting or in the countryside, were the ones focusing more on digital 3D mapping. A good example of this is represented by Here (see Figure 14) - currently the mapping division of Bentley - and Aurora, a North American company in the market for driverless trucks, which produced an "Aurora Atlas" hosting their mapping efforts (see Figure 13).

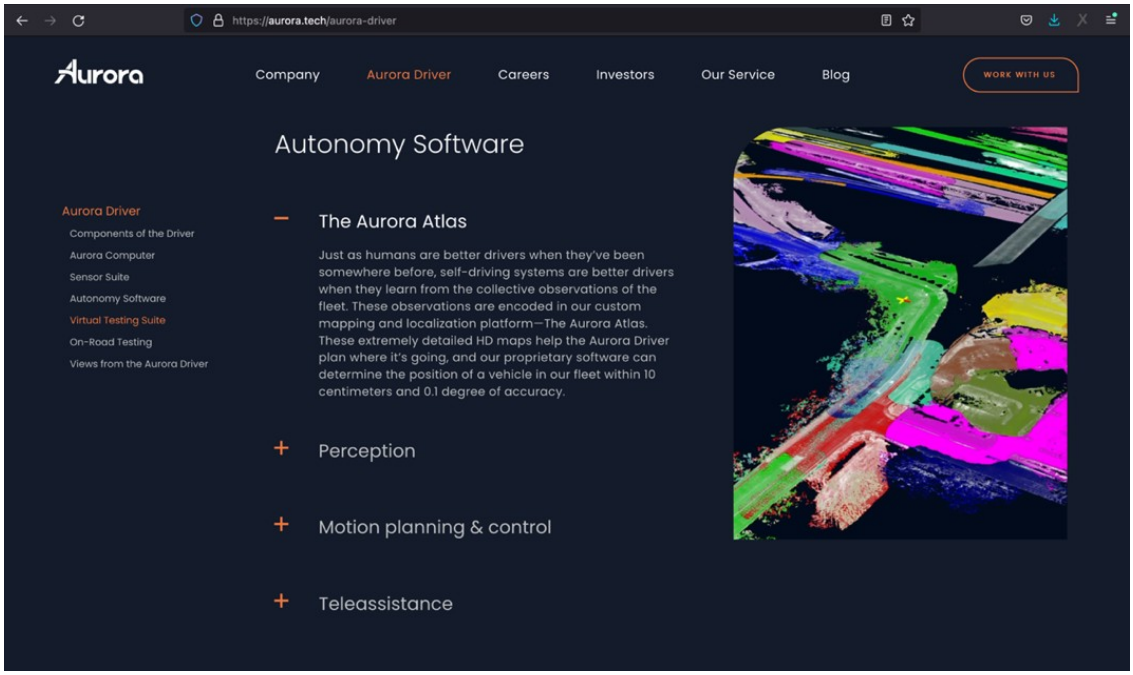


Figure 13 Screenshot taken from Aurora's website https://aurora.tech/aurora-driver last accessed 26/5/22.

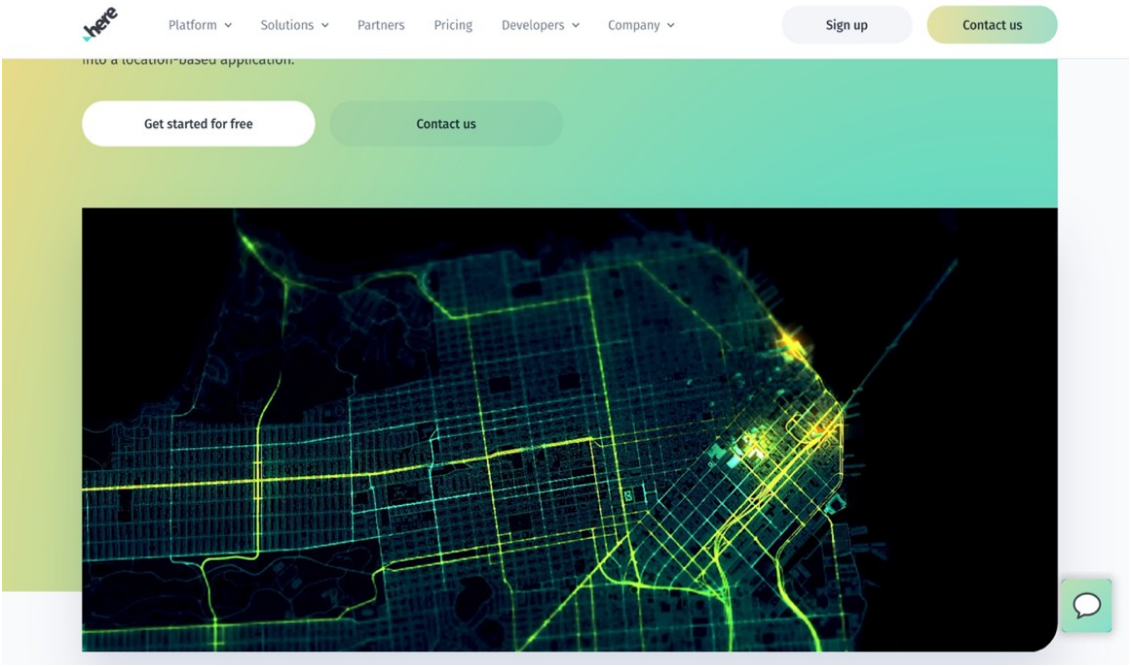


Figure 14 Screenshot taken from Here's website https://www.here.com/platform/map-data last accessed 22/4/22.

It appears that the vast majority of the companies, more than half of the ones surveyed, decided to integrate Lidar imaging to showcase their precision in the mapping of the urban landscape. Inside this pool, three of them used the iconic value of specific sites in famous cities in a move that seemed to capitalize on place advertising (Fleming and Roth, 1991) (see Figure 15). Nonetheless, a small minority opted for a smaller scale to display their aptitude for different applications. Whereas the regional scale was preferred by companies opting more to focus user attention on their prowess in this form of digital mapping.

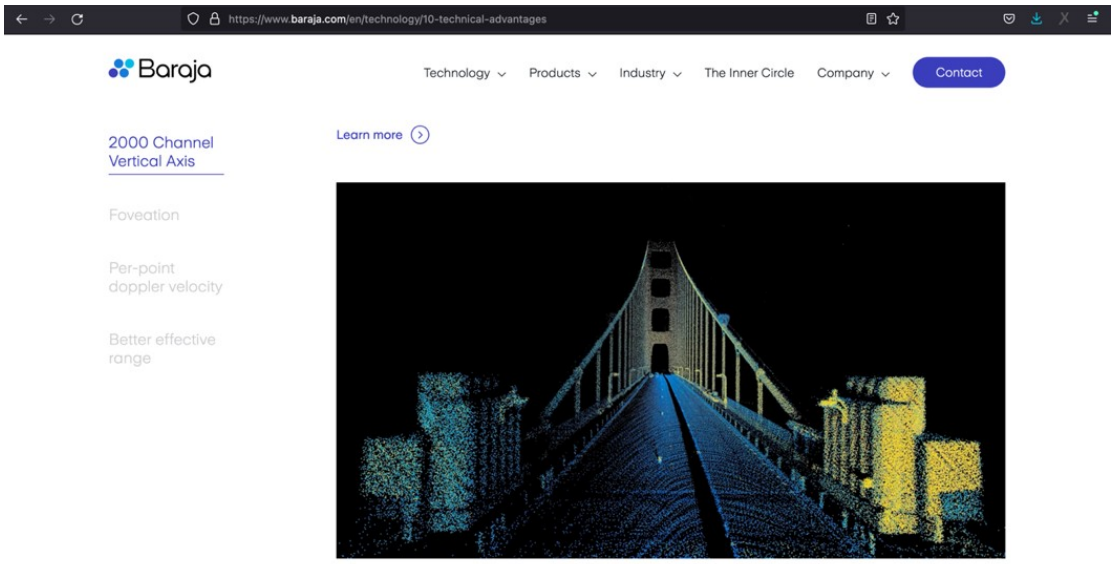


Figure 15 Baraja https://www.baraja.com/en/technology/10-techical-advantages last accessed 11/5/22.

Taking interactive functionality into account, among eighty companies, only three presented visuals with some degree of very limited interactivity.

Both Mobileye (Figure 17) and Undestand.AI (Figure 16) showcased an embedded split image that can be manipulated by the user by moving the cursor between the two parts. For both of them, the split screen moves between an image of the street photographed by a simple camera, while the other shows the continuation of that scene captured through the Lidar sensor. For instance, Mobileye shows the fusion between Lidar and radar data.

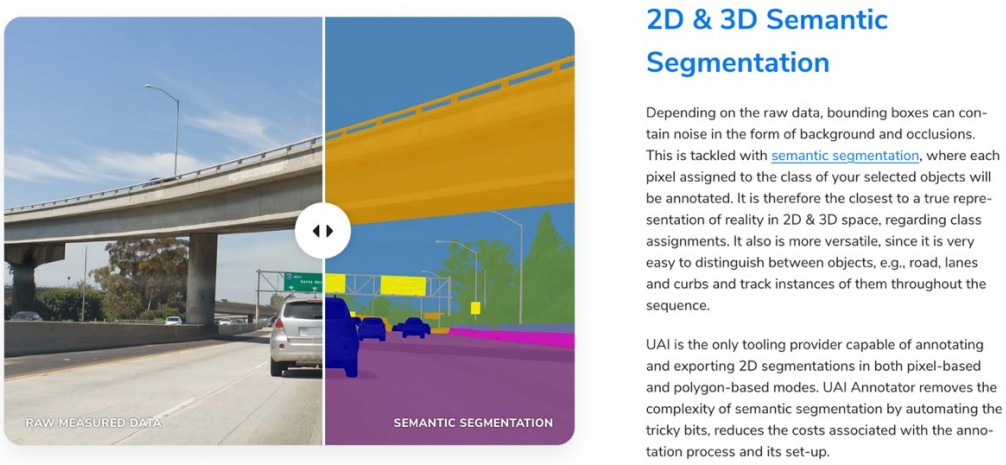


Figure 16 Screenshot taken from Understand.ai's website https://understand.ai/product.html last accessed 10/5/22.

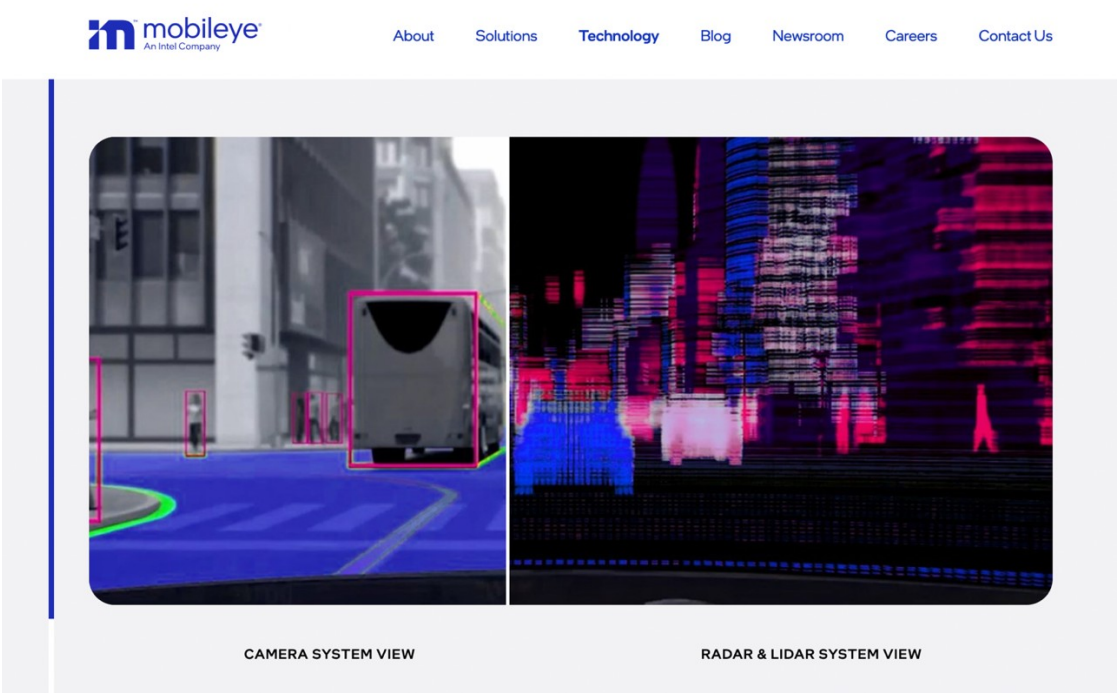


Figure 17 Screenshot taken from Mobileye's website https://www.mobileye.com/technology/ last accessed 2/5/22.

Luminar Tech, one of the "lunicorns", is the only firm presenting a 3D rendition of a view of Las Vegas in 180° that can be explored by the user moving the cursor, granting a quite

impressive ghostly view of the famous city in the neon colors of a point cloud. The 180° rendition gives an immersive feel that internet users might have grown familiar with through the use of videogames or other VR application.

The fact that less than four percent of the sampled companies decided to exploit the interactive potentiality of Web 2.0, a feature promoted by advertisers (Voorveld et al., 2011; Voorveld et al., 2013; Zollet and Back, 2015) and carefully analyzed by geographers (Bittner et al., 2013; Crampton, 2009; Graham, 2010; Leszczynski, 2011), while the ones that decided to use it did so not in an informative manner, but for the aesthetic feel, once again, gives a precise indication towards the meaning of the presence and relevance of Lidar imaging in the identity building of these brands. Even when a limited form of interactivity is present, it only allows the end user to experiment with the world seen through a laser eye to the degree that the highly manipulated image allows. Once again, these visuals are displayed primarily for their suggestive allure, rather than their information content, emphasizing their persuasive rhetorical impact, embedded in their appearance and presence. As an exception to this conclusion, it should be noted that Ouster, at the time of the survey, presented a link to download a data set to explore in autonomy by the viewer, but I do not possess the appropriate competences to evaluate the substantiality and deeper meaning of this decision from the company. It's interesting, anyway, that the brand that pushes more on the aesthetic side of their branding is also the only one, to my knowledge and at the time, to present a public sample of their dataset.

4.7 Website survey results: other hybrids

One of the difficulties in surveying the sample was most certainly the ambiguous ontological status of the images shown. As illustrated above, in some instances, it was hard to define cases of Lidar imaging and count them in the result. To make this dilemma

clearer: is a manipulated point cloud still a point cloud? Isn't it something else already? An image that has been hollowed out of its scientific origin and that persists on the surface as a mere trace of its appearance. A hard, methodological question that, within the framework of this survey, has been resolved by considering valuable, for the quantifiable results, only the images clearly extrapolated from demonstrative videos embedded in other pages.

Nonetheless, it's impossible not to mention the fact that most of the companies that didn't make it into the final count of the survey used some form of visual strategy in their brand identity building.

In the first instance, there are firms, like Aeva, that, along with the classic Lidar imaging, present video reconstruction in 3D of the sensing vehicle along some desolated highway crossing the country or big intersections in a busy metropolis (see Figure 18).

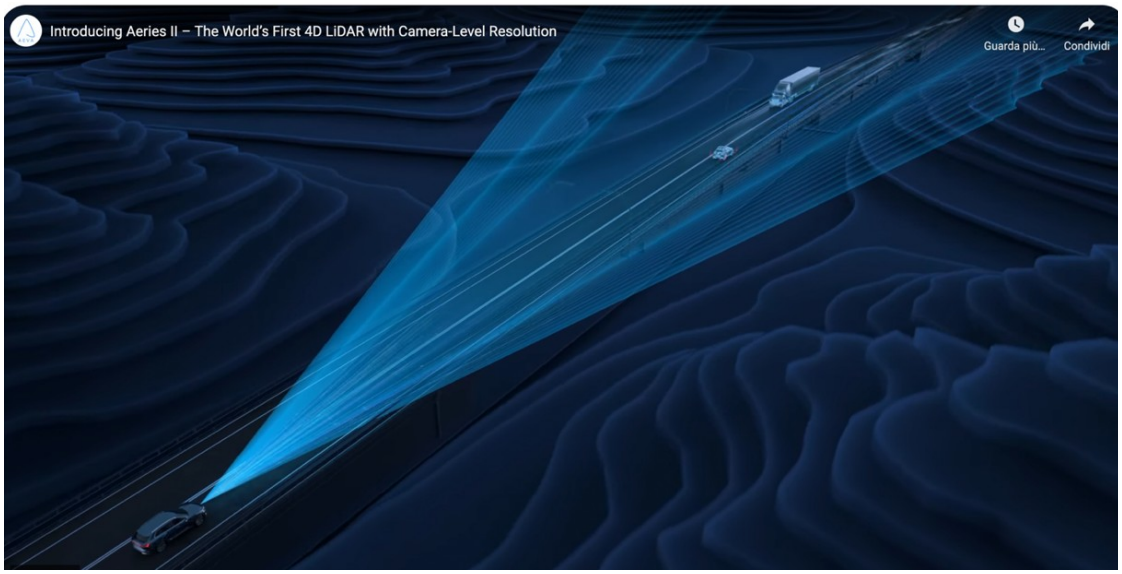


Figure 18 Screenshot taken from a video embedded in Aeva's website https://www.aeva.com/aeries-ii/ last accessed 1/6/22.

Usually, this is also the preferred visual marketing strategy of brands that want to focus on how sleek the car looks and how seamless the process of acquiring data and putting it to efficient use is. Among those are Zoox and Aurora.

Aptive, Cruise (see Figure 19), and Argo (as we already saw) share the same aesthetics with the trace of a point cloud superimposed either on a camera still, a picture, or a 3D realistic simulation. In many instances, for example, when the start-up is also invested in algorithmic training for software, examples of 3D simulation appear, substituting the more common view from cameras equipping the sensing vehicle. This is also apparent in some segments of Velodyne's demonstrative videos, one of the most famous North American Lidar sensor producers.

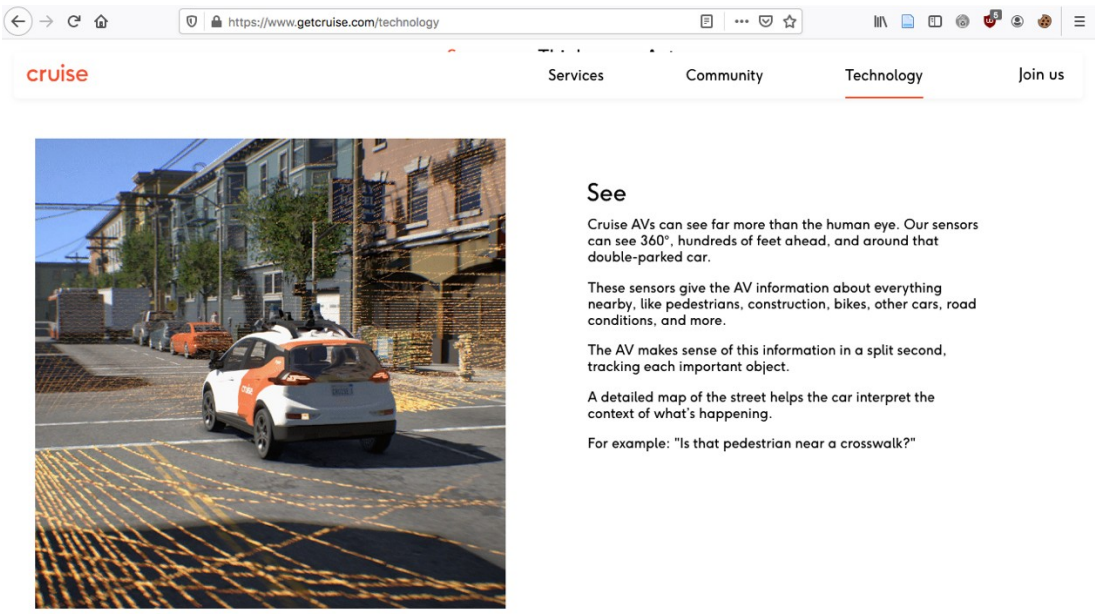


Figure 19 Screenshot taken from Cruise's website https://getcruise.com/technology/ last accessed 20/4/22.

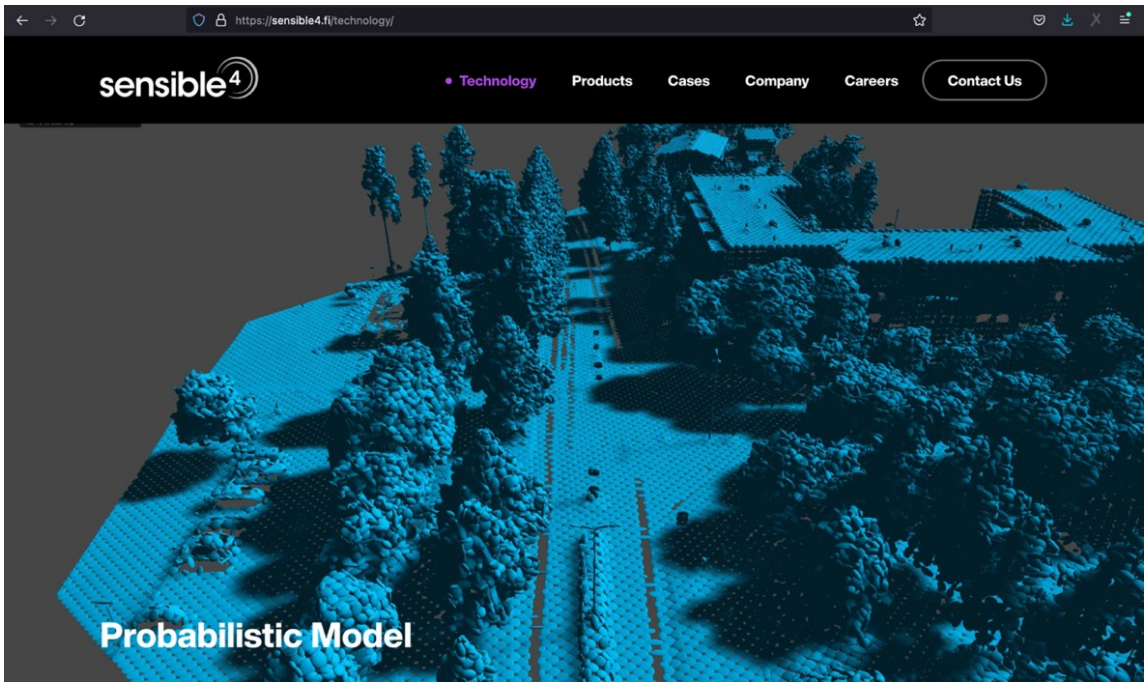


Figure 20 Screenshot taken from Sensible4's website https://sensible4.fi/technology/ last accessed 15/4/22.

Sensible4 displays such an interpolated point cloud while advertising their probabilistic modeled algorithm that it's impossible to call it a point cloud; it is something entirely different (see Figure 20). This complete departure from the popular point-cloud aesthetic also shows up in videos: Fast Tree 3D presents a good example of this. To explain the process of vehicle planning, a driverless car is reduced to a graphic rendition of its three-dimensional form, completely white, and is shown while it sails through a gray-green road, surpassing cyclists, once again stripped of all realistic features and reduced to smooth three-dimensional regular shapes. In these cases, the alluring look of three-dimensionality is paired with a minimalist, sleek graphic rendition, which seems to recall images of the future as they were imagined by the Modernists (Lasch, 1983), compared to the dystopian mood of disruption evocated by the point cloud and its neon coloring.

Once again, all these instances, although impossible to enlist in the presentations of Lidar imaging for marketing purposes within the framework of this survey, as they present an image *of* Lidar rather than an image *from* Lidar, contribute to the powerful aura of three-dimensional representation of space (Makantatis et al., 2019) in the futuristic mood that start-ups seek to conjure.

4.8 Conclusion

Lidar imaging upsets common geographical categorizations. In the first place, it was important to define a provisional space for this kind of visualization in the cartographic arena. After that, considering the site of display of such images, a recognition of persuasive cartography was necessary to prepare the conceptual terrain for the subsequent internet survey results. Analyzing eighty currently operative websites from businesses involved in the Lidar market—only the ones operating in the automotive sector were included—it was possible to first grapple with the presence and prominence of 3D imaging. From the results, it appears that including Lidar point clouds on website pages plays an important role in the marketing strategy of a substantial number of Lidar companies. After considering the kind of functionality expressed by such images, it was possible to establish that none of the firms deployed them for their scientific value or their informational meaning. It must be concluded that Lidar imaging occupies screen space solely for its aesthetic value, because of what I termed its *auratic presence*, and this is a great departure from the mixture of information and rhetoric that traditionally imbues persuasive cartography.

Lidar imaging is mostly characterized by an aesthetic quality that links it to disruptive imaginations of the future (Mladenović, 2019), placing the form of temporality it conjures

within the phenomenon of 'cyberboosterism', often criticized by geographers (Dodge and Kitchin, 2000; Nederveen Pieterse, 2021; Parker, 2015). While brands seek to propose an image of the car of tomorrow that is potentially already present, they propose, through the different scales produced by available demonstrations in surveying, a panoply of spaces to be automated. While automation is already present in the industrial sector (Fatima et al., 2022), the urban site remains the envisioned final site of deployment in connection with the development of smart cities (Yvkoff, 2020), breaking free from the bounded model of the urban lab that has constituted the backdrop of R&D experimentation to this day (Dowling and McGuirk, 2022). The city envisioned by the proposers of full autonomy is a place completely invested in data governance and fully integrated into the Autonomy of Things (Rangwala 2021, 2021b).

Nonetheless, the vision for a fully automated urban site remains as vague as ever, as the ecosystem of start-ups and firms demonstrates its fragility in the constant turnover. While some young companies seek merging as a survival strategy, the financial market has recently seen the fall of well-established top players in the midst of a recession. This has brought about a general shift in the Lidar market for autonomous vehicles, with a renewed focus on more reachable goals like the development of an Advanced Driver Assistant System (ADAS) to be integrated in electrical cars, which is nowadays at the forefront of the political agenda. The lack of a sustainable model of business development might also be attributed to the difficulties imposed by the change in the surveying monopoly that the development of automation imposes, as well as a certain resistance to change that has always been part of car culture on an affective (Mom, 2014) as well as rational level (Featherstone et al., 2005). A rigidity that has also been charted as a constructed paradoxical limitation of freedom through the policing of the automobile system that was

sold as a means to reach new horizons of mobility freedom (Seo, 2019), ending up promoting inequalities along the lines of race fractures. Seo's account of the changing political habits that the USA government had to negotiate and enforce upon the white middle class represents a great case in analytically reconstructing and thus making visible a whole set of norms that nowadays are taken as obvious but that were constructed as such through a radical change in society, through legal norms. History tends to elide the difficulties of changing societal norms and habits, while it's necessary to underscore how these modifications, benign in appearance, can end up having malicious effects on specific segments of the population.

Careful consideration of the effects of technologically augmented forms of driving within the urban site, and beyond, should critically be taken into account, especially considering how algorithms, in spite of their neutral aspiration, carry within them racial bias (Noble, 2018; O'Neil, 2017). It's also important to note that steps are being taken to counteract biases in the development of machine learning models, but this may not be enough (Benjamin, 2023; Caton and Haas, 2020). Indeed, as seen up until this point, seemingly small and trivial changes in infrastructure and mobility may have unforeseen bigger impact on certain people. Which is way, as stated in previous chapter, challenging specific parts, not working as intended, is not enough. The whole system, in its design principles, structure and functioning processes, should be put under scrutiny.

Critical urgency is also intensified by the observed shift in economical patterns in geographical knowledge production. The underscored, ever-changing nature of the financial landscape offered by Lidar producers represents just one facet of larger paradigm shifts involving the state and industrial monopolies as the main producers of maps. Critical geographer Wood (2010) makes a compelling argument for this larger historical reconstruction, describing the design and diffusion of the North Carolina

Highway Map, and the preponderant involvement of the state in the creation of preferred modes of transportation. Noting how the maps from 1979 and 2006 are not visually improved, he argues for the state's retirement from the surveying effort. Akerman (1993) complicates this framework, highlighting how the construction of highway maps in the USA has been influenced from the beginning by automobile and highway-related private companies and semi-private associations. The promotional content of these maps tried to depict the driver of the highway as a pioneer conqueror, but the design itself of the map, favoring certain routes and concealing local ones, ended up, during subsequent decades, making the highway into a mundane feature of travel, naturalized and reduced to invisibility (Akerman, 2002).

With the liberalization of GPS and the subsequent diffusion of in-car satellite navigation systems (Cohn, 2009), the production of maps fell into the hands of private companies like TomTom and Here. This informal monopoly was broken by the advent of Google Maps (McQuire, 2019b) in the first place, and then thanks to crowdsourced navigation apps. With the rise of Lidar imaging in the making of HD maps for different levels of autonomy, these companies are coming back to the forefront of mapping production and consultation for navigational purposes. These paradigm shifts, which happen at an organizational level as well as at a material and discursive one (Holford, 2019), are fraught with frictions and fragilities that, despite the methodological challenges they pose, need to be investigated.

As shown by the survey results', at the moment, Lidar companies are generally not exploiting the possibilities of Web 2.0, except for aesthetic purposes, but with Apple including a Lidar sensor on their mobile devices (Tara 2022), as well as the announcement at CES 2023 (van Rees 2023) of the acquisition of Civil Maps by Luminar, one of the biggest players in the Lidar niche, this may change. Civil Maps is an HD mapping start-

up, founded in 2015, that leverages crowdsourcing in the production of their three-dimensional mapping operations. These news stories gesture towards a diffusion of a technology that is difficult to foresee and that calls for an accurate analysis of the discourse sustained and reinforced by this kind of geovisuality production.

In this complex set of problems, the aim of this chapter has been to establish the foundation of the Lidar archive, as a methodological gesture, in trying to define the fuzzy boundaries of this object of study as a critical geospatial site of inquiry. From this first and rather descriptive encounter, it has emerged how, in the provisional dichotomy between information and persuasion, Lidar geovisualities are deployed on websites in a manner that allows for the emergence of a category that goes beyond the two extreme ends of the spectrum: the digital aura. However, having approached this slippery aesthetic quality of Lidar, it still is not much informative concerning the kind of imaginary that supports Lidar and construct its necessity in the development of full autonomy within the urban site. This will be the goal of the next chapter, which will then grant the basis to go deeper within the digital materialities of Lidar sensing.

The main objective of the thesis isn't to portray Lidar sensing as a dangerous device. The ultimate goal is to frame this technological tool within a larger cartographic critique of how managing space entails an intersection of knowledge and power that needs to be made explicit so to, possibly, avoid unforeseen unfair declensions of the effects generated by a wider deployment of this visual-spatial tool, implementing correcting tools, as it is being done in the realm of machine learning.

Chapter Five

Coding and decoding Lidar imaging online

5.1 Introduction

During the 2019 Introductory Lecture of the MIT Self-Driving Cars series, Lex Friedman, a notorious advocate and educator around artificial intelligence themes, explained the reasons why engineering research around unmanned vehicles should be a priority[14]. As he talks, with a chalkboard filled with complex mathematical formulas as a backdrop, a power point is visualized, summarizing his argument. On an ancient-looking map representing Europe and Africa without any kind of political or geographical annotations, the title says that the mission of the introduction of automation in mobility is concerned with "improving access, increasing efficiency, and saving lives". As he goes on talking, the first of his arguments regards how traffic represents the worst and most mundane cause of stress and negative emotions in human society. Finding "smart" solutions to the problem of traffic would instantly produce improved efficiency. Nonetheless, the most important aspect of the research in the field, according to the data scientist, is the possibility of resolving the problem of accidents on the street. "Here's a counter: every 23 seconds, somebody in the world dies in a car, an automobile crushes. It should be sobering; it is a thing for me that I think about every single day." As the timer arrives at 0.00, a number is added to the three circles below, counting deaths within the day, the month, and the year. According to the lecturer, this should provide the groundwork for his review, spanning from Waymo to Tesla, to other automotive firms that reached results in terms of miles accumulated during testing. He proceeds to show different kinds of predictions towards a meaningful and impactful deployment of fully autonomous

[14] full video available here: https://www.youtube.com/watch?v=sRxaMDDMWQQ&list=PLrAXtmErZgOeY0lkVCIVafdGFOTi45amq
Last accessed 18/3/2024.

vehicles, from the very optimistic, positioning full scalability within a couple of years — a goal not reached — to the most pessimistic, placing it within a decade from now. But among these two extremes, the lecturer focuses upon a form of human-centered autonomy that assists the driver when their attention span plummets[15].

Friedman goes on to show experiments developed at MIT, where drivers have been tracked with cameras to determine when the assistance system should kick in to provide support and conversely alert the driver when a situation difficult to resolve for the machine requires human intervention. This is, according to the engineer, fundamentally a matter of human-robot interaction, which requires an understanding of the psychology of the human subject involved and is currently deployed with deep learning algorithms

[15] The speaker, Lex Friedman, at min. 19.24 of the speech available at the link provided in the preceding note, claims how the categorization he is presenting is related to the widespread taxonomy provided by the Society of Automotive Engineers (SAE), the preferred one in USA and EU. The taxonomy can be summarized as follows (see https://www.sae.org/blog/sae-j3016-update las accessed 18/03/24). At Level 0, there is no automation, and all driving tasks are performed by the human driver. As we progress to Level 1, vehicles offer limited assistance, such as adaptive cruise control or lane-keeping assistance, but the human driver remains fully responsible for monitoring the environment and controlling the vehicle. Level 2 introduces partial automation, where the vehicle can assist with both steering and acceleration/deceleration simultaneously under certain conditions, such as on highways. However, the human driver must still be ready to intervene when necessary. Moving to Level 3, we find conditional automation, where the vehicle can manage most aspects of driving in specific situations or environments, but the human driver is required to be ready to take over control if requested by the system. Level 4 represents high automation, where the vehicle can perform all driving tasks under specific conditions without human intervention. These conditions might include well-defined environments like geo-fenced areas or dedicated lanes. However, human intervention may still be necessary in certain situations or environments outside the predefined boundaries. Finally, Level 5, or full automation, represents the ultimate goal where vehicles can operate autonomously under all conditions without any human intervention. In a Level 5 autonomous vehicle, humans are passengers, and the vehicle handles all driving tasks, regardless of the environment or circumstances. It's worth noting that current technologies typically fall within the Level 2 to Level 4 range. Additionally, the transition between autonomy levels often involves complex human-robot interaction challenges, regulatory considerations, and technological advancements.
Hopkins and Schwanen (2021) propose a complete interpretational framework to discuss normative effects arising from automation typologies. In his own way, Friedman too, in his speech, offer his own reinterpretation of the levels of automation. He explains how the SAE categorization is useful for inaugurating discussions around automation, especially at a policy-making level, while it's not very useful around issues concerning design and engineering of the overall systems needed to provide safe machines. At min. 20.15 of the linked speech, he proposes his own categorization, comprised of two levels of AI systems. Such levels are meant to distinguish the responsibility/liability of the vehicle, at a legal, experiential and algorithmic level. He considers level 2 systems, within which, according to him, ADAS system are part of, as the first level of AI system, in which humans are at the center of driving as legal, experiential, and algorithmic subjects. Conversely, level 4, which he describes as fully autonomous, although constrained, is part of the second category of AI systems, in which the algorithmic stack of the vehicle is considered fully responsible. To simplify, for Friedman, only two levels are important: level 2, semi-autonomous, that corresponds to his first AI category, and level 4, that he considers fully autonomous, and corresponds to his second category of AI systems. The first category corresponds to vision, and is based on cameras, the second category is based on mapping, and hinges upon Lidar. In the rest of the chapter I will be referencing the SAE categorization without Friedman own interpretation. It should be noted that the only reason why I write about the levels of automation here is circumscribed to how it impacts theoretical framework surrounding the digitalization and automation of the urban site, and how this is done through a digital cartographic logic, hinged upon the production and diffusion of Lidar geovisualities.

derived from game theory. The fully automated level, that foresees humans exclusively as passengers, requires a different approach, mainly rooted in the deployment of Lidar devices, as maps producers. The lecturer leans towards a preference for the development of semi-autonomous systems, based on cameras and computer vision, as they are good enough to save lives and it's supported by good enough available technology, also explaining how "our world is designed for humans' eyes", so, at a logical level, committing to the development of systems that employ visible data makes the most sense. Nonetheless, it's impossible to scientifically determine the amount of visible data incoming from the camera that would be needed to allow the deep learning algorithm to solve difficult problems. Therefore, in terms of accuracy, consistency, and reliability, a case should be made in favor of Lidar systems, as they showcase the most accuracy and reliability. Lidar-based approaches require "taking constrained roads and mapping the heck out of them, understanding them fully in different weather conditions, and so on". The drawback is that once again, "a lot of car Lidar data" is needed, and currently there are not enough cars equipped with Lidar sensors to collect the necessary data.

The development of driverless cars is framed in this speech as a problem concerning the management of traffic, with the aim of overall improving citizens lives by removing stress factors as well as inequality in accessibility to transport (Wigley and Rose, 2020; Sourbati and Behrendt, 2020). Nonetheless, the most important benefit of research is the possibility of eliminating the risk of injury and death, improving overall safety and security. It's interesting to note how, despite all these discursive efforts, the larger public still perceives autonomous cars as somewhat upsetting, untrustworthy. A notable example is offered in the latest movie by writer and director Sam Esmeil's *Leave the world behind* (2023), which offers a scene with Teslas, fresh out of the warehouse, as an optimal vector for hackers to block the highways around the city of New York during a cyberattack.

Detractors of this area of research have argued against the possibility for autonomy to achieve such goals, referencing episodes in which humans were killed by algorithmic mistakes (Bissell, 2018). What is important to note here, within the aim of this research, is how Lidar imaging is framed as a mapping endeavor based on extracting data and visualizing it for human control over the machine learning algorithms. In the next section, I will discuss how scholars have been framing questions arising from the development of driverless cars within the urban site, and then I will reconstruct how Lidar imaging is deployed to sustain a supporting discourse that in turn conditions research and development (Wilken and Thomas, 2019).

The discourse around Lidar geovisualities has been framed by scholars as "sovereign" (Hind, 2022:58). But this sovereignty hardly describes how the imaginary is factually developed by Lidar manufacturers and supporters. To reach a better understanding of what the commercial discourse around Lidar imaging entails, I propose in this chapter a discourse analysis of the eight biggest players in the Lidar niche for driverless cars. The main goal is to code and decode the themes that frame Lidar imaging as the pivotal digital-visual technology in the attempt of digitizing mobility. To reach this goal, the websites have been analyzed to highlight how statements by companies envelop Lidar imaging with the intended effort of depicting the deployment of this sensor as the key to achieve safety within the city of the future. The discourse analysis proposed in this chapter has been designed to deepen the critical understanding of Lidar geovisualities as an example of persuasive cartography, advanced in the previous chapter. Before showing the results of the analyses, I propose a literature review of the development of the driverless car in the datafication of the urban site, to depict the context that works as a backdrop of the imaginary of Lidar, as it is commercially developed online.

5.2 Driverless cars and the urban site

The ultimate goal of developing fully autonomous driverless cars appears to be far away from being reached. Nonetheless, versions of the technology are currently used in automated vacuums, delivery pods, prosthetics for disabled people, warehouses, mines, and other industrial sectors, as well as in highly constrained environments, like specific pathways within college campuses and airports (Kellerman, 2018). While autonomous driving figures among one of the features of AI urbanism (Cugurullo et al., 2023; Palmini and Cugurullo, 2023), scholars argue that such technologies have managed to escape the bounded nature of the deployment of unmanned vehicles (Dowling and McGuirk, 2022). Nonetheless, fleets of unmanned cars are not a common sight in cities, they still have to respond to unresolved questions of algorithmic nature, in regard to decision-making within an environment that is difficult to control and predict (Brown, 2017). Levels 3 and 4 autonomy, within pre-selected paths, can exploit mapping through Lidar with an inch to inch precision, in the organization of the space to be automated. Moreover, this model of deployment avoids questions around ownership of cars that would become central to the transition to fully autonomous vehicles in the urban landscape (Fagnant and Kockelman, 2015; Cavoli et al., 2017; Legacy et al., 2019). To deploy a substantial fleet of unmanned vehicles, the infrastructure of the city would need networks to allow for communication from the single car to traffic management devices, as well as full communication between each vehicle (Legacy et al., 2019). And this level of interconnectedness still wouldn't resolve ethical problems regarding the philosophy to be embedded within the decision algorithmic hub of the machine to solve with speed critical situations presenting themselves on the road (Bonnefon et al., 2016). Lately, engineers have been circumnavigating philosophical issues by simplifying the task: when the car perceives an obstacle, it stops (Borenstein et al., 2017). It's difficult to produce speculations about how this would affect traffic management (Mladenović, 2019).

With the goal of escaping the bounded level 3 area of implementations, startups have been trying to develop services of robotaxis, unmanned vehicles providing transportation on demand. This strategy seemed a viable way to slowly introduce new forms of car ownership, introduce fleets in urban sites, provide miles for companies' statistics about safety, and slowly introduce the urban population to the new technology (Bansal et al., 2016; Krueger et al., 2016; Tussyadiah et al., 2017). However, with Argo.ai, one of the biggest competitors in the field, officially closing down operations in October 2022, it became evident that, in spite of bank and capital venture projections, the priority of introducing robotaxis in cities did not have a sustainable business plan and failed to provide concrete answers to urgent questions arising from the mobility sector. Big Lidar companies like Luminar and Oxbotica commented on the bankruptcy of Argo.ai, noting how the development of robotaxis was never within their primary goals, even though their previous contracts with Audi and Addison Lee, respectively, seem to testify to the contrary. As of today, while prototyping and testing for level 5 autonomy go on at intense speed, most Lidar companies have started providing their devices for ADAS, systems for the development of level 2 or 3 of autonomy, to be considered within the diffusion of electric cars, and systems of control and entertainment within the vehicles. Within this field, the biggest commercial success is represented by Tesla, which doesn't use Lidar, preferring to implement visual systems and deep learning (Stilgoe, 2017; 2018).

Firms involved in the production of Lidar for autonomy have been deploying this spatial technology along with a radar renaissance in autonomous vehicles not designed to transport passengers on the road. The favored model for level 5 autonomous driving, right now, is the conceptualization of automated highways (Kaur and Rampersad, 2018). In the development of autonomy at level 3, the so-called man-in-the-loop, the human subject that needs to remain vigilant to supervise software operations, requires an ecosystem of

sensors to be deployed in the exterior as well as the interior of the car to allow for self-tracking of the driver (Swan, 2015; Lanzing, 2016). Lidar mapping is therefore necessary to map and recognize objects and humans on the road and within the car in order to obtain safe navigation. In areas where semi-automated driving can be used, mostly highways, the vehicle still needs to be able to alert the driver in case of problematic situations. Also, the system needs to be able to "read" the driver to either stimulate their attention span or kick in to substitute them. On top of the collection of data required for these navigational operations, these systems, through dashboards and screens, can provide passengers with a fully equipped entertainment and advertising system (Miller, 2017; Hind and Gekker, 2022).

As such, driverless cars have been read as a chapter in the platformization of the urban site (Dodge and Kitchin, 2007; Steinberg, 2021).

Platform urbanism is the multi-layered outcome of the diffusion of the business and social model of the social platform at the economic, social, and political levels (Barns. 2020). This means that, within a framework built upon corporations and private organizations that collect, sort, move, make sense of, and sell data, various goods and services are shared or sold through app interfaces available on smartphones (Barns, 2017; Yeo and Lin, 2020; Rose and Willis, 2019). Platforms are becoming widely established intermediaries and can be seen as an evolution of the ever-elusive smart city. I turn to the typology offered by Caprotti, Chang, and Joss (2022) to make sense of this paradigm shift within the urban landscape: after a decade of smart city modeling that got implemented upon older urban paradigms providing site-specific stratifications, platformism intervenes to complicate the framework. The main difference between these data-driven models is how the space of the city is embedded in their concepts. Smart cities have proven to be site-specific; scholars have had difficulties giving an overarching general definition and

focusing their attention on data practices and operations, divided by tasks, actors involved, and localization (Caprotti and Cowley, 2019). The main paradigm shift offered by platformism is that companies seem to offer a universal template that can be applied in many different places. This is true for social media platforms, delivery platforms, entertainment platforms, platforms for buying all sorts of objects, and platforms that connect citizens to municipalities. Given this universal quality of the technologically mediated framework proposed, which can be read within modifications in global declensions of capitalism (Srnicek, 2017), it's also important to enumerate the ways in which platformism is paradoxically imbricated with the urban site. Despite their universal intermediation patterns, every service offered by a platform relates to the city as a place: there is usually a starting location, an address, and a final location, once again an address. Moreover, the platform has as its main focus the urban site because of the density of demands that it proposes. Adding to that, especially in services connecting rural locations to main centers, it proposes a digital expansion of the city, or, in the case of booking services for flights and staying places, makes every city already present everywhere.

Platform urbanisms also present the same drawbacks as the smart city in terms of the digital divide, the promotion of social inequalities, and a general unease that comes with the operations of data mining involved (Elmaghraby and Losavio, 2014; Monahan, 2018; Nugent and Suhail, 2021). These changes have brought scholars to talk about an evolution in surveillance practices (Alvarez Leon, 2019). The proposed models span from Latour's Oligopticon (2012), when surveillance is reserved to the ruling few, to Andrejevic's automated surveillance (2019), in which the places of articulation of the material and social networks are punctuated by sensors for data mining, to infrastructural surveillance (Gekker and Hind, 2020), especially tied with the development of smart mobility within the city. Moreover, effects of urban platformization share with the smart city model the

importance of flows of data and the invisibility of their infrastructure (Plantin et al., 2018), which become apparent only when it stops working due to accidents, breakages, and failures (Larkin, 2013). In addition to that, studies that connect the current development of new data standards within the field of data science to produce commensurate archives with the latest global economic trends are lacking. Nonetheless, it is crucial to remember that within such trends, "the fabric of urban life, commercial interactions, policing, and justice are all part of our archived and mined world" (Galison and May, 2015). It's also important to note that the material side of the networks supporting urban platformism should be properly investigated.

As highlighted above, semi-autonomous forms of driving are currently slowly making their way within the positioning of the urban site as a space to be, more than connected through the Internet of Things, fully automated. However, as of today, this idea remains a utopian technocratic dream that inhabits, at a smaller scale, highly bounded spaces. Within the framework of the smart city, companies are testing their fully autonomous technology in test-bed simulations, primarily (Fayjie et al., 2018). These simulations are designed by 3D artists specifically for the task of testing the suite of navigational sensors embedded in the prototype. In other cases, digital twins of cities (Winter and Tonko, 2019) are deployed as testbeds. 3D models of the cities are sometimes produced by the highly specialized mapping companies that are also committed to the development of car perception through Lidar (Xue et al., 2020). The companies surpass simulation tests and then deploy their technology in real-life testbeds, which are usually circuits predisposed to peripheral or rural areas (Marres and Stark, 2020). Only after passing these tests is the prototype for the driverless car put on the road in highly bounded areas to be mapped inch by inch before the actual unmanned test, which still requires a human supervisor. A few studies have been produced around using urban areas as living labs or experimentational

areas for prototypes (Karvonen and van Heur, 2014), focusing on how the local population is rarely involved (Marres, 2020) and on how the production of an area as a testing laboratory completely alters the urban ecosystem, turning it into an abstract place that cannot provide useful data for engineers. These testbeds are also usually highly secretive; they are only publicized after the experiment is concluded, making it hard to develop critical inquiries.

Having seen how the driverless car, in its various levels of automation, is imbricated within the smart city and processes of platformization, it is important to note that the relationship between these data processes and the zoning of cities seen as living labs requires further elaboration.

In the meantime, having enumerated how the development of driverless cars is connected to material and informational infrastructures, with their limits and constraints, it might be possible to advance a first hypothesis in which the deployment of this technology seems to exhibit a desire to reshape the urban form and bring it to a novel form of ordering, thus to respond to a splintering (Graham and Marvin, 2001) phenomenon brought upon by the very economic processes that seek to search for a solution to the narrative of crises within the urban site (Zook, 2017). In the words of a driverless car company that no longer exists, the desire is to bring *cosmos* into the perceived *chaos* of the urban site (see Figure 21).

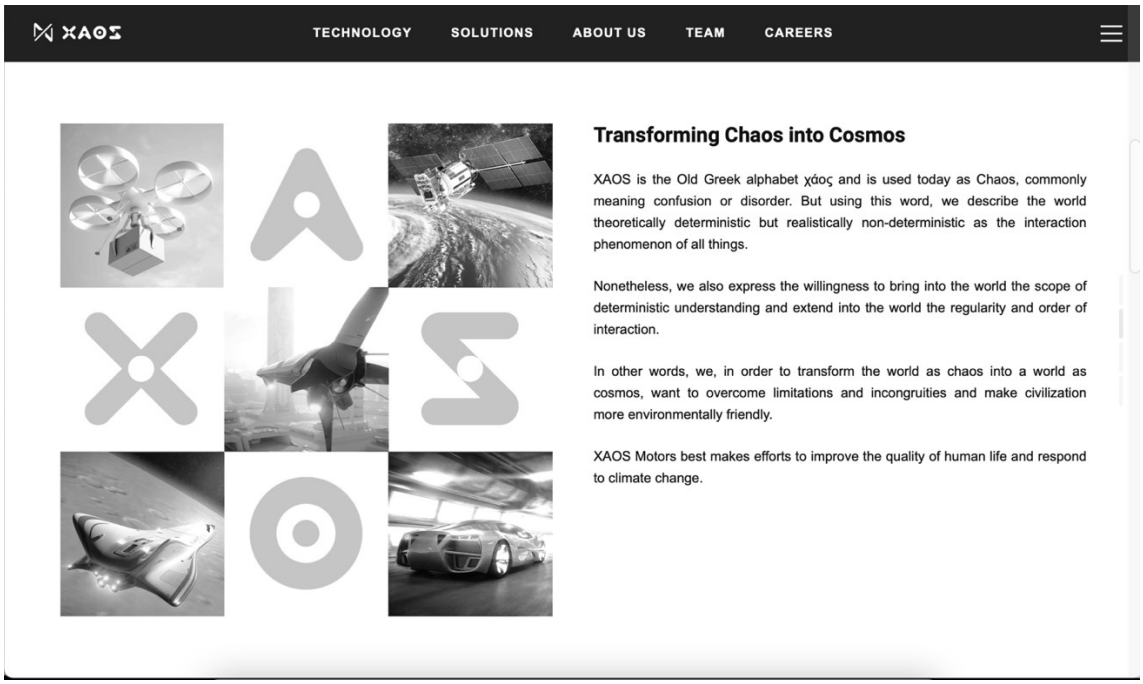


Figure 21 Screenshot taken from Xaos motors's website http://xaosmotors.com/aboutus last accessed 21/07/2021.

Having highlighted the material difficulties around the development of driverless cars, the discourse developed to sustain them is enthusiastic and rather tightly arranged.

Glossing over the fact that Lidar technology, leading this field of research as well as the mapping endeavor that sustains it, is the product of highly entwined military and commercial objectives, posing political problems (Taeihagh and Min Lim, 2018; Gössling et al., 2018) – which will be tackled in Chapter Six, Seven and Eight – it is considered the solution to a panoply of pressing problems within mobility in the city and beyond: traffic, accessibility, and, most of all, death rates connected to accidents. Considering the suggested cautions underscored in the conclusion of the previous chapter, following studies on algorithmic biases (Noble, 2018), on the basis of the moral insistence on the development of technology for life and death reasons, it might be possible to foretell a speculative future connotated by different kind of fractures, akin to the idea expressed by *necropolitics* (Mbembe, 2011). As it will emerge during the analysis of the

companies' websites, Lidar geovisualities are not concerned with individual feature of the objects that need to be recognized. However, it will become clear how this very powerful tool can be deployed with dire effects in the spatial management of contested liminal spaces, like borders (Mezzadra and Nielson, 2013).

Nonetheless, to avoid speculation, in what follows, I will conform myself to the discourse produced by manufacturers online, showing Lidar imaging as a form of digital auratic persuasion. To my knowledge, only one study has been produced around Lidar imaging (Hind, 2022), with a focus on the kind of machinic sensemaking arising from sensors sensing space and the kind of failures they can fall into when humans supervising get distracted.

My study, instead, in this chapter, will expand on the discourse sustained by Lidar imaging and, in the following chapters, it will tackle the materiality of perception through an analysis of the images outputted and the hardware and software architectures proposed by manufactures, reconstructing the normative power of such images in reshaping conditions of experience of the city, inscribed within the grammar of materials that compose them.

5.3 Coding Lidar imaging discourse online

Having considered the presence and prominence of different versions of Lidar imaging, and the position and layout of them inside the complex structure of websites from the previous chapter, it's now possible to deepen the critical understanding of the deployment of Lidar geovisualities. I considered the websites of eight high-profile companies involved in the development of Lidar for fully autonomous driverless cars. Having considered the kind of visuals deployed by these companies, and how the displayed

images are enveloped by persuasive statements, I advance seven categories to further the analysis: safety, time, performance, vision, intelligence, universality, and revolution. None of these categories is deployed on its own; rather, a coupling of two or more of the categories emerges from the play between visuals and text or speech. All the categories are compatible with each other, building a strong interwoven discourse. For this deeper analysis, I've chosen eight of the unicorns making up the fragile Lidar ecosystem in the attempt of providing a smaller sample to allow for more in-depth analysis that could also stand the test of time (Anlitycs Insight, 2022; CBInsights, 2018; Coldeway, 2017; Retours, 2017). The companies selected are: AEye, Aeva, Innoviz, Luminar, Ouster, Velodyne, Quanergy, and Pony.ai. In the last trimester of 2022, Ouster bought Velodyne, and Quanergy declared bankruptcy, however, their sites are still online.

I briefly outline each category while highlighting the key effects in meaning that they aim to produce in the website user:

1. *Safety: "We* save lives".

It is fundamental for all the companies assessed to disenfranchise themselves from the first accidents that happened in the earlier phases of driverless car development. Detractors of this technology often insist on the impossibility of trusting machines. Challenging this view was not enough for developers in the field; a complete rebuke of the accusation was necessary. Companies have maximized their effort in testing their products to prove, accumulating impressive amounts of kilometers, that their software is able to discern and behave much better than human drivers. That's the undeniable power and precision of algorithms. The numbers provided by testing constitute the basis on which it is possible for several producers to claim that further development and global dissemination of the technology are not only desirable but indeed a moral necessity, as regulating traffic through algorithmic governance not only could but will certainly save

lives endangered by unregulated driving. Furthermore, Lidar is also safe in the sense that it unhinges the debate surrounding privacy, making it useful in security matters as well. Point clouds, in fact, are impossible to use for profiling individuals based on their specific aesthetic features. Nonetheless, crowd management still posits urgent questions (Klauser, 2016; Nishiyama, 2018). Indeed, exploiting the specifics of Lidar imaging, anonymity is preserved by focusing on flows of objects (people, goods, vehicles, and so on) and their patterns. Whereas the idea that a driving environment is superseded by an algorithm has been debated, the concept of representing flows, to understand and govern them (Cubitt, 2014; Sutherland, 2018), poses a new challenge to the critique of discipline and surveillance that still hasn't been fully developed by scholars in its connection to Lidar geovisualites. I will explore such issues in Chapter Eight.

2. *Time: "We* can predict and control the future".

Lidar mapping is intertwined with time in various and complex ways. At a technical level, there is a technical need for speed. Speed in data acquisition, and then in extraction, interpretation, and planning. Speed is central to the functioning of the first rhetorical strategy too. Many video demonstrations of the whole technological environment rotating around Lidar and other sensors want to highlight the speed at which the software is able to represent and, most importantly, understand the environment. But this first definition of speed is not enough. The challenge among producers is to shrink the distance between reality and its digital copy, bordering on real-time. In this manner, Lidar mapping supersedes cartography: not needing manual updates ever so often, it establishes a constant flow of data that goes continuously from input to output, in an ever-expanding learning experience that can take into account both the ever-changing facets of the real world and the evolution of its digital copy, often used to run simulations and tests. Testing algorithms is another realm in which time assumes a substance that is slightly different

from reality. In fact, to sustain the claim to safety, it is fundamental for the planning software to be able to discern the objects and, thus, predict their behaviors. In this two-fold relationship with time, companies can select for themselves a claim to the future. Having built a solid foundation in the necessity of their work, having freed themselves from the constraints of timely map updates, and being backed by the power of machine learning in predicting the future, they can appropriate for themselves the time that is yet to come. This means, once again, two major things: the results of their mapping efforts will never be outdated on a material level. In a more complex, cultural, and imaginative way, they can lay claim to reshaping the future of everything connected to mobility, from individual trips to industrial logistics across the globe (Beer, 2018; Rosa, 2010).

3. *Performance: "Our* product is the best available on the market".

To beat competitors, it's necessary for every brand to illustrate how their approach is different and better. Usually, to achieve this, two visual strategies are used. The first one consists of illustrating technical features (detection range at reflectivity rates, vertical and horizontal resolution, points per second, laser wavelength, angle accuracy, beam divergence, field of view coverage, and resilience to other beams) allowed by the specific Lidar architectures deployed (either spinning, MEMS, solid-state, flashing, phased, or fully digital) with numbers, icons, and brief explanations of every specification necessary to achieve high-confidence data detection, acquisition, and extraction. Secondly, an example of a point cloud is presented, either in the form of a static image, an animation, or a demonstrative video. This is a core moment for a brand to verify their claims to safety and to further sustain the necessity of their technology to restructure how to navigate through different environments to provide maximum efficiency, productivity, and reliability (Bruno, 2009).

4. *Vision: "We* see what you can't see".

Lidar mapping is often shown to accompany statements around the vision capabilities of a certain hardware-software ecosystem for autonomous driving. Usually, the idea being promoted is that, even though point clouds have an appearance that is quite counter-intuitive for the human to read, given the high-confidence data extraction allowed by architectural solutions, the machine is capable of seeing more and better (Lenoir et al., 2022). The machine can detect very small objects with an accuracy that is not subjected to any kind of fluctuation or variation. Not only that, but being able to "complete", through the complex set of algorithms embedded in the software objects that might be partially covered can ensure a higher degree of safety in all situations.

5. *Intelligence: "We* can think what others can't think".

Lidar mapping is a nodal developing point in all the spaces that exhibit the ambition to be defined as "smart": this is true for urban settings in general, for airports and docks, for industrial warehouses, logistics hubs, and mining sites. The vocabulary "smart" is actually an acronym that, in its full form, reads as "Self-Monitoring, Analysis, and Reporting Technology". It indicates all those objects that can extract data from the environment through an array of sensors and make sense of that information through various algorithmic methods to interact with humans and other machines. The term ended up becoming synonymous with "intelligent", because of the appearance that inanimate objects can be filled with a sort of agency and animation of their own and interact with other sentient beings or objects. The more "intelligent" an ecosystem is, the more it is capable of extracting meaning from datasets without committing errors. Intelligence must be designed into the architecture of the object to allow for clean data extraction within the

material constraints provided by the hardware. When it comes to intelligence, companies avoid implying that machines are more intelligent than humans. In this instance, a more poetic idea of being able to see and therefore think what cannot be seen and, consequently, imagine the future is favored. Along with the sensor-human eye metaphor, software is often compared to the cerebral cortex involved in processes of vision in humans, persisting in a highly debatable anthropomorphizing of machines (Chun 2011; Hunger, 2023).

6. *Universality:* "*We* can transcend every limit."

Lidar mapping is rooted in the robotic field called SLAM (simultaneous localization and mapping). In its most basic form, SLAM is a technique for mapping an environment while keeping track of the mapmaker's location. Robots, like vacuums cleaners and last-mile pods, which are all Lidar-equipped, can automatically determine their current location in space and navigate to a new area thanks to this mapping and positioning technique. Using a Lidar sensor, the depth and geometry of the objects in the scene are natively collected (Arshad and Kim, 2021). Different sensors measurements are integrated to achieve a map of the surrounding space and predict the estimated trajectory of the measuring object. This map can be either in two dimensions or in three dimensions, composed of points, lines and surfaces. Lidar data can also be used to understand the structure of a three-dimensional volume. In this instance, a volumetric algorithm connects visual data (in the form of voxels, see Agoston and Agoston, 2005) and builds a map using edges and planes recorded by the device as features rather than close-by pixels, as photogrammetry does. This mixture of relative spatial relationships, to be projected upon, where needed, with locational coordinates, allows for great versatility, adaptability, and flexibility of SLAM, connected to the numerous variations in the hardware and software architecture needed to carry out the task. This complex mix makes available a technology that is extremely

localized and at the same time can be deployed anywhere, obtaining similar results. Companies exploit this feature by showing how their sensors work in different settings, transcending the limits of surveying imposed by formal or material constraints (points of view, connectivity, accessibility, depending on the technology deployed).

7. *Revolution: "We* will change the world".

Lidar mapping examples, often incapsulated in longer videos that deploy different kinds of visual contents along with text or spoken speech, aim to establish the idea of absolute novelty in the user. With the compounded effect produced through the divulge of impressive numbers and cutting-edge benchmarks, and with the support of images of point clouds and demonstrative videos illustrating the technology at play, the companies want to show the various applications of the autonomy they can reach in different settings, ranging from an urban setting to an agricultural and industrial one. These claims are rarely sustained by specifying the level of autonomy the specific brand can sustain with their proprietary technology, favoring the depiction of a close future in which digital twins will be irreplaceable in every aspect concerning mobility (Zook and Blankenship, 2018). Such grandiose claims are probably manufactured to sustain a more general rhetoric that wants to move beyond the biggest obstacle on the route towards full autonomy: the infrastructure needed to sustain it (Kaur and Rampersad, 2018; Rana and Hossein, 2023). Indeed, for driverless cars for individual consumption to become widespread, a radical change in the way we organize and govern logistics will be needed, especially in highly complex and layered urban settings. Thus, images of lightweight sensors strategically applied at intersections and their resulting point clouds depicting traffic patterns intend to facilitate the idea that, given the necessity—already established through *safety*—of their products to reach progressively larger markets, the world will indeed have to change. Moreover, each company has a desire to solidify their position in the race towards

autonomy by claiming their uniquely effective way of breaking through competition; this is done either by comparison or by completely ignoring others' available architectural strategies. Nonetheless, bold claims need to have their visual counterpart, usually provided by a digital representation of the landscape with the added visual strength conveyed by the vertical gaze of a drone.

5.4 Decoding visual strategies in promotional Lidar maps

The seven categories outlined in the previous section will be applied to eight companies that have been chosen from the set surveyed in the previous chapter. The selection has been made according to their annual revenue; the ones taken into consideration have exceeded one million USD according to fiscal year 2021. All the companies exhibit on their websites visual proof of their work, and, at a superficial level, such props look very similar, although they vary in the degree of prominence and relevance accorded to them in the overall promotional strategy, as already established in the previous chapter. A more detailed analysis shows a greater variety between modes of presentation and the connotative meanings accorded to visuals, along with a difference in preferred media. In what follows, I'll discuss each preferred visual strategy with relevant examples.

Five out of the eight companies considered for this analysis rely on different textual and visual strategies to establish the safety of the technology they propose. In fact, the problem of safety is considered central in the debate concerning the opportunity to develop driverless cars within urban areas. While detractors usually point out episodes in which the control system of the car was unable to avoid human accidents that ended up causing deaths, promoters of the technology tend to use the power of numbers to prove why algorithmic navigation, through its diffusion, might be a central key to putting an end

to the spreading of fatal or severe accidents involving drivers and pedestrians in traffic. While it's not possible within the scopes of this research to establish who is right and who is wrong within the debate, it's appropriate here to analyze the visual and textual strategies the companies' have deployed in order to communicate a sense of safety around the products they propose. As it will be shown, companies tend to sustain the discourse concerning safety with a combination of one or more of the different categories coded in the paragraph above.

Among the companies using just one of the codes to promote an overall idea of safety is Velodyne. The Silicon Valley-based Lidar technology startup called Velodyne Lidar was established in 2016 when Velodyne Acoustics was split off. David Hall established the business in 1983 as an audio company that specialized in subwoofer technology. The business started creating a range of Lidar devices after 2005, focusing on those that made use of multi-beam spinning Lidar scanners installed on cars. Velodyne is considered the original manufacturer of so-called legacy Lidar for the development of driverless cars after winning the mythical DARPA Grand Challenge. A media archeology of this historical event will be provided in Chapter Seven. As of now, it's important to say that, given its history and its extensive selection of Lidar sensors that offer flexibility in parameters and a high quality of the outputted images, Velodyne Lidar is well recognized on a global scale. Nonetheless, it's also important to note that, by looking at more than 100 videos from the company on their Youtube channel (some of which will be analyzed in detail in Chapter Six), it's impossible not to notice a subtle shift that took place in 2021, from a focus on the automotive sector to small robotics. This might be an effect of a settlement between Velodyne and Hesay over a patent battle, the news of which has been reported on their site as of July 20, 2020. In 2021, the company had to face financial storms, and, as of now, Velodyne has been bought by Ouster.

Given this shift, Velodyne Lidar devotes the largest part of the homepage to a video of a four-armed robot walking with an array of sensors covering what looks like the head of a large insect (see Figure 22).

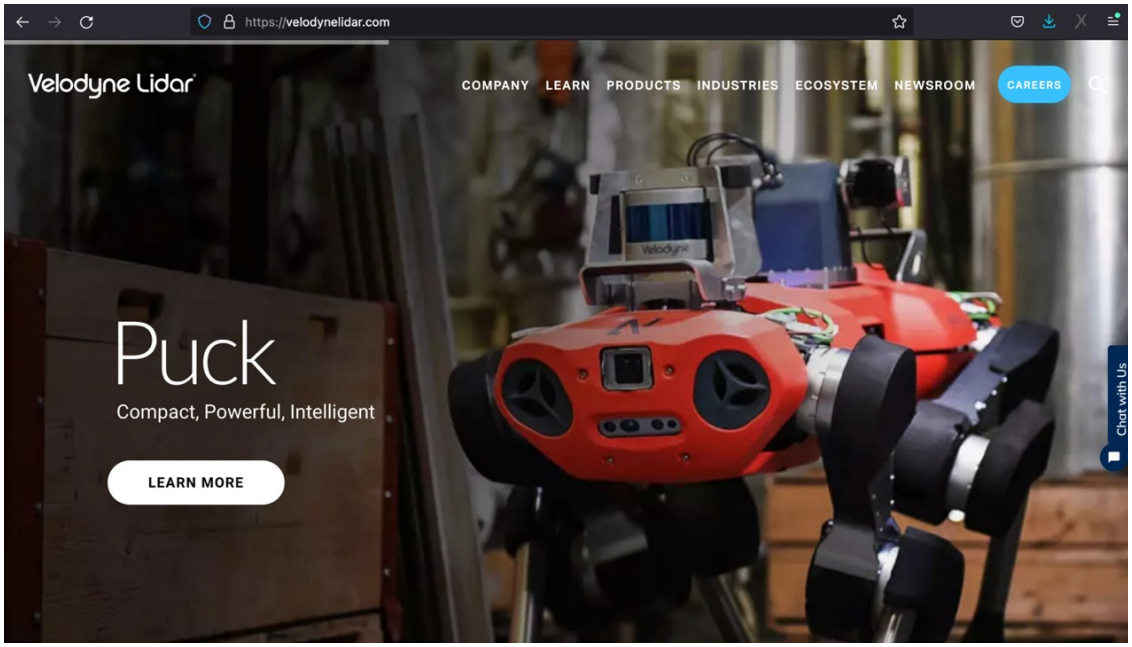


Figure 22 Screenshot taken from Velodyne's website https://velodynelidar.com last accessed 22/05/22.

All of the partners show little snippets of their work, either in the form of point clouds or with reproductions of their 3D models. Nonetheless, here, Lidar maps don't have greater relevance compared to showing the actual devices mounting the sensors. A video highlights the mission of the company, which is "science in the service of safety" and "creating smart technology for a world in motion", but presents the same images already shown in previous animation around the homepage. Referring to the codes enlisted in the previous section, it's noticeable how Velodyne, in order to sustain their claim to safety, leverages the notion of intelligence, which, in this site, is connotated as the product of applied scientific research. By leaving the word in their promotional materials to the many partners deploying their Lidar devices, it looks like the company tried to deflect

responsibility. Here, safety is the product of science, therefore it is objective, and, as such, it is fruitfully put to work by many who can account for their experiences (see Figure 23).

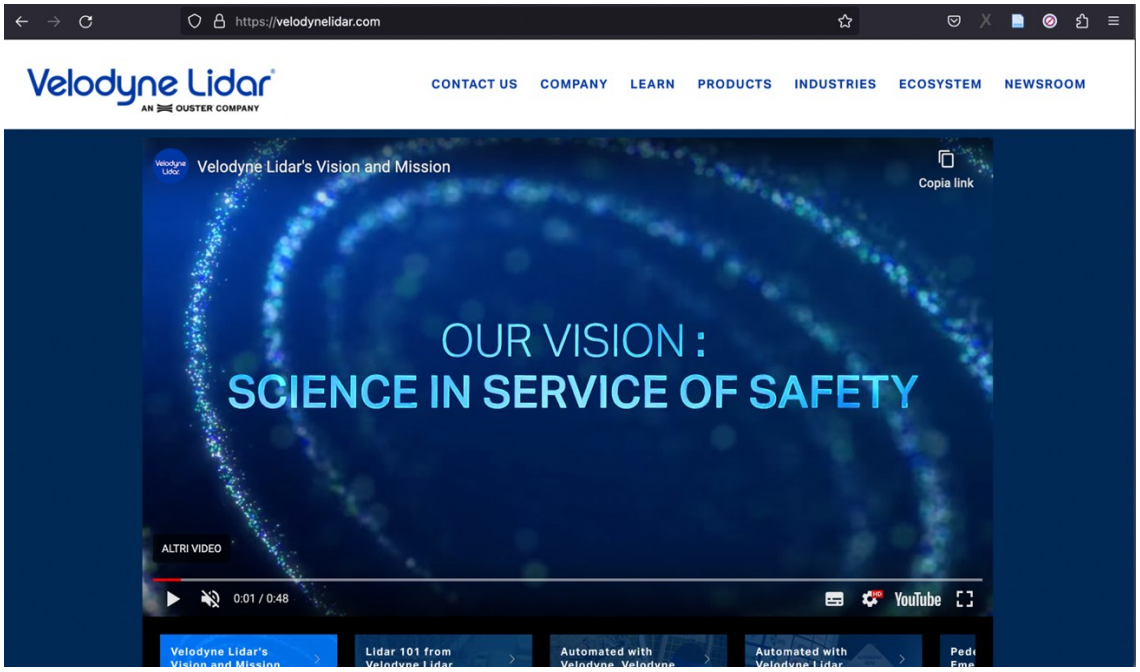


Figure 23 Screenshot taken from a video embedded in Velodyne's website https://velodynelidar.com last accessed 22/05/22.

Quanergy is another company that uses just one code to sustain their claim to safety; however, their take on safety is strongly tied to concerns around visibility and privacy. Located in Silicon Valley, Quanergy Systems is a publicly traded technology business that creates Lidar sensors and associated technologies. The company was founded in 2012 and agreed to a reverse SPAC merger in June 2021 to go public. But their financial adventure didn't hold up for long, as the company submitted a Chapter 11 bankruptcy filing in December 2022. Regardless, Quanergy can be considered a central player in making the Lidar sensor fully digital. As it will be best explained in Chapter Seven, Lidar sensors have within themselves optical components, namely mirrors and lenses, necessary for their functioning. Quanergy created a fully digital Lidar sensor built on optical phased array (OPA) technology. This innovation allows for full scalability in production and may

be used to track in real-time objects and people accurately and secretly. In the precise words of Quanergy, "visibility = security". The main field in which the company is specialized is, in fact, the monitoring of critical infrastructure, and an ample part of their branding is focused on explaining the advantages of Lidar over different kinds of monitoring technologies.



Figure 24 Screenshot taken from a video embedded in Quanergy's website. https://quanergy.com/applications/security/ last accessed 26/05/22.

Scrolling down, a section of their website provides different links to different applications for their sensors. The second one, dedicated to smart spaces and infrastructure, presents a video along with an in-depth paragraph about crowd management (see Figure 24). In the video, a voice explains how Lidar is critical to the management of a city because of the layers of complexity that come with the global economy. After that, point clouds are shown in their capacity to represent an entire road from above and a more localized space crowded with pedestrians. A similar layout is

present in the page dedicated to "mapping", although this time a moving point cloud with a shadow filter on top occupies a larger part of the screen. Once again, a video explains how Lidar is, at its core, a mapping technology that can generate a large amount of detail and have several applications, including industrial, agricultural, defensive, and transportation (see Figure 24).



Figure 25 Screenshot taken from a video embedded in Quanergy's website https://quanergy.com/applications/smart-city/ last accessed 26/05/22.

It can be argued that, for the company, safety doesn't concern primarily the well-being of pedestrians and city dwellers. The idea of safety promoted here is concerned with the management of crowds and the visualization and direction of patterns of flow among people. It's safety for spaces and objects, it's security. Safety through vision and visibility also represents an attempt to downplay the dangers involved in crowd tracking. As an argument can be made for the fairness of Lidar tracking, not being concerned with the individual features of people and objects being tracked, thus making issues of gendering and racial profiling look like problems finally resolved. However, it's important to note

that in 2017, according to Forbes, Quanergy was involved with the Trump administration to provide Lidar technology to surveil the border between the USA and Mexico (Ohnsman, 2017). In the end, the agreement was not implemented; however, this constitutes a grave and important example of why critical inquiries regarding Lidar imaging are important and necessary.

Lastly, among the companies using just one code to sustain their discourse around safety figures Pony.AI. "Autonomous mobility everywhere" dominates the center of the Pony.ai homepage. In the background, a video rolls showing the silhouette of a dramatically illuminated branded car with the typical shape of a sensor on top (see Figure 27). Aerial shots show the vehicles of the automated fleet in urban, suburban, and desert settings, to signal the versatility of the software stack offered by the company (see Figure 26).
In the page dedicated to the specific products offered by the company, a vector design of a car seen from above with concentric rings projecting out depicts the working of the sensors equipping the sensing car (see Figure 29). A brief paragraph alongside explains how intense testing of technology has allowed the company to have a product ready for scalable production on the global market. Another section explains how the brand has an active service of robotaxis already available, and below that, a map of the globe in the classic Mercator projections is shown, although slightly bended to simulate the roundness of a globe.

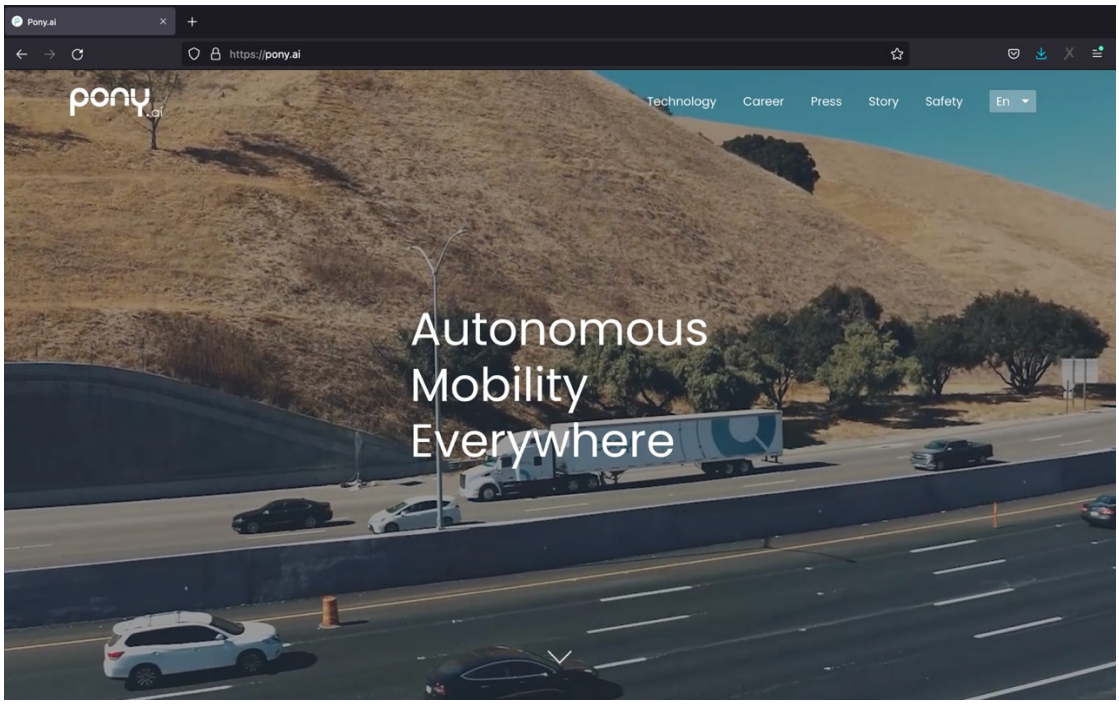


Figure 26 Screenshot taken from Pony.AI's homepage https://www.pony.ai last accessed 28/05/22.

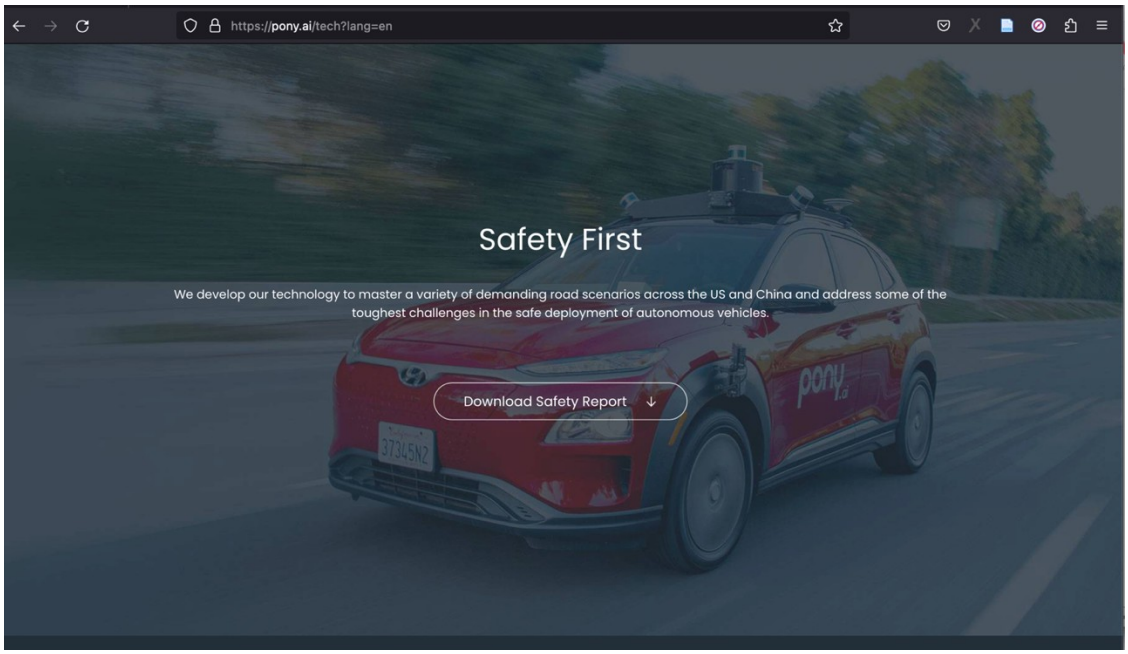


Figure 27 Screenshot taken from Pony.AI's homepage https://www.pony.ai/tech?lang=en last accessed 28/05/22.

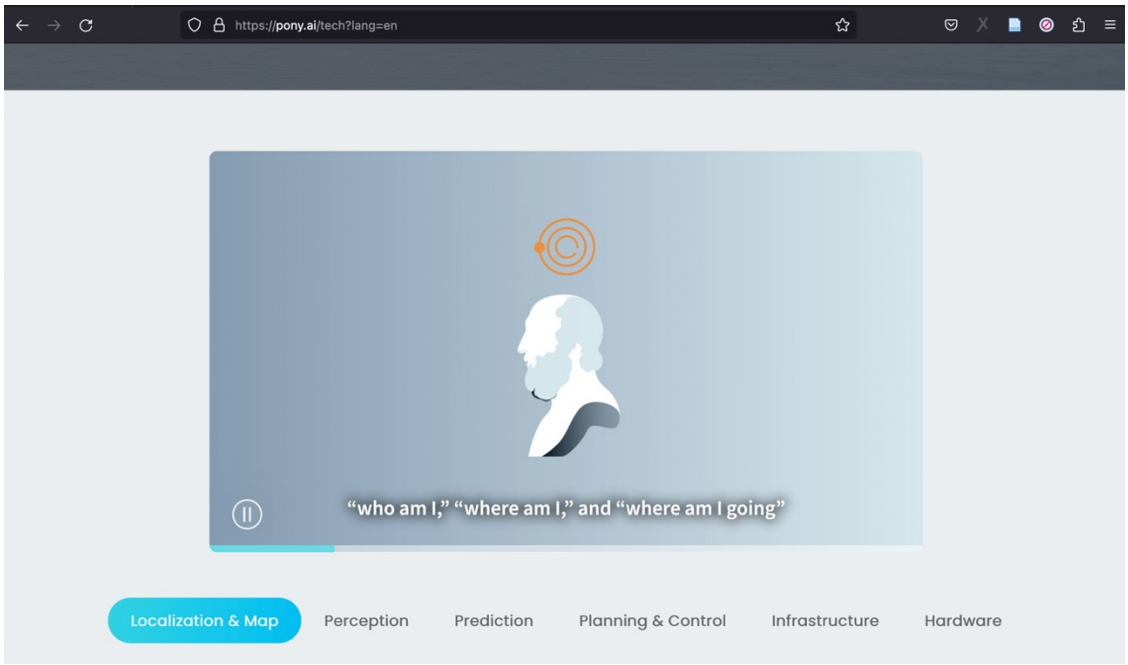


Figure 28 Screenshot taken from a video embedded in Pony.AI's website https://www.pony.ai/tech?lang=en last accessed 28/05/22.

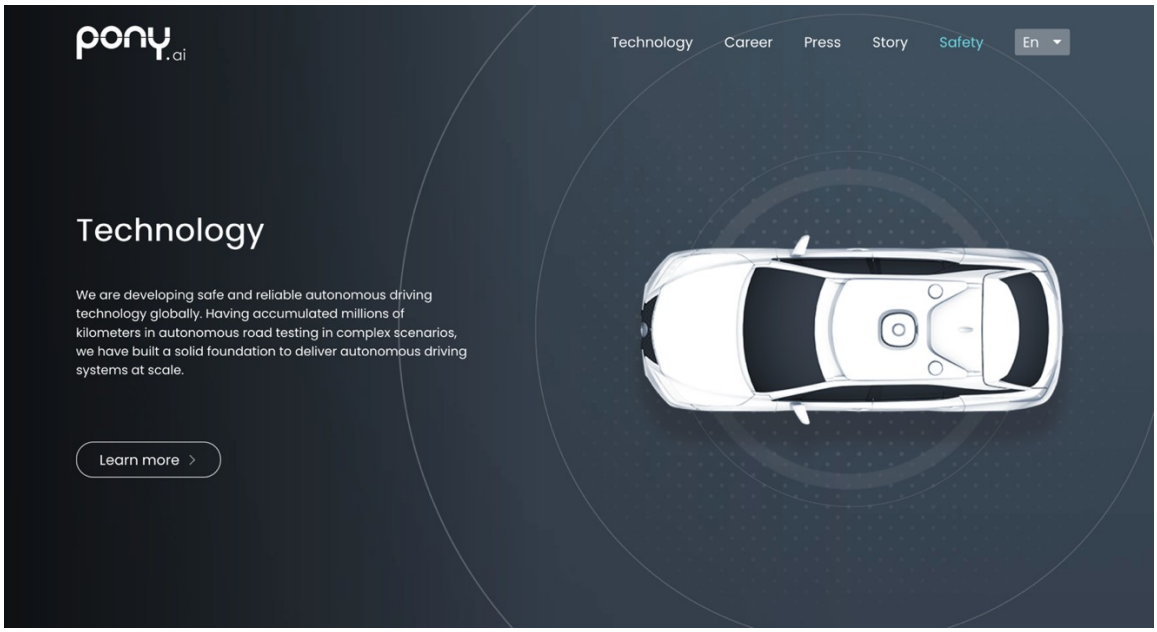


Figure 29 Screenshot taken from Pony.AI's website https://www.pony.ai/?lang=en last accessed 28/05/22.

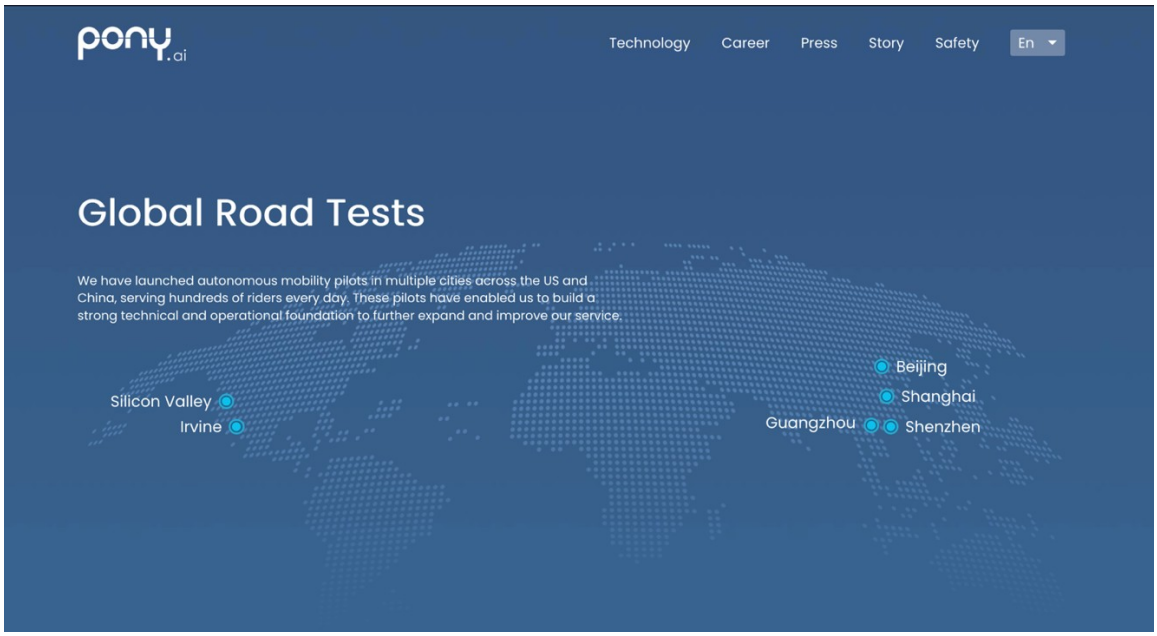


Figure 30 Pony.AI https://www.pony.ai/?lang=en last accessed 28/05/22.

The usual shape of the continents is produced by the juxtaposition of little squares. A legend proves the globalist inclination of the company by highlighting how the brand has completed road tests in two cities in the United States and four cities in the Republic of China (see Figure 20). Going to the page "technology," a vector graphic video explains the challenges faced in making a vehicle autonomous (see Figure 28). The machine needs to be able to answer philosophical questions, vector graphics is deployed to illustrate the different modules making up the core of the machine: emphasizing the need for infrastructure and hardware. Below this explanation, composed of a total of six videos, there is another section comprised of two videos. The first one shows a test road for a Pony.ai self-driving car while encountering a sandstorm in Shangai. A split screen shows the different views from a camera on the left and a visualization of the whole system. The bird's-eye view of the car offers a different perspective than the one captured by the camera. The machine learning algorithm, thanks to its intelligence, is able to discern the points that need to be taken into account and the ones that need to be ignored in order to

safe navigation, thanks to the high amount of data collected in road tests. The second video utilizes the same layout and visual strategies, showing a full-hour test road in Guangzhou without interruption and minimal editing intervention. This company doesn't utilize any point clouds to support the claims made on the homepage, opting for a different visual strategy comprised of vector graphics, videos, and the exhibition of the visualizations that the end user would see while being driven in one of their driverless cars. The idea being forged is that the machine is a highly intelligent object, capable of philosophical questioning and supported in its navigational endeavor by an abundance of data that, aggregated in intelligent ways – giving priorities to certain objects – can make it more than safe.

There are other two companies heavily focused on the theme of safety, and these are AEye and Ouster. These two high profile companies deploy a branding strategy that is a little more articulated than the others, using a combination of two or more codes to sustain claims to safety.

AEye's visual branding opts for a sober look, mainly rotating around vector illustrations, accompanied by simple but effective sentences and short paragraphs, illustrating the specific strengths of the products they position on the market. The headliner recites "Our vision for a safer future", in an almost neon green that stands out starkly against the hegemonic white of the website (see Figure 31). The motto of the company immediately conjugates three of the codes identified in the previous section: vision, safety, and time. This brief dense sentence stands near different vector illustrations that are very simple in the choice of colors. An embedded timer shows different kinds of these pictures, illustrating in a simple way the different applications for the technology advertised by the brand (see Figure 32).

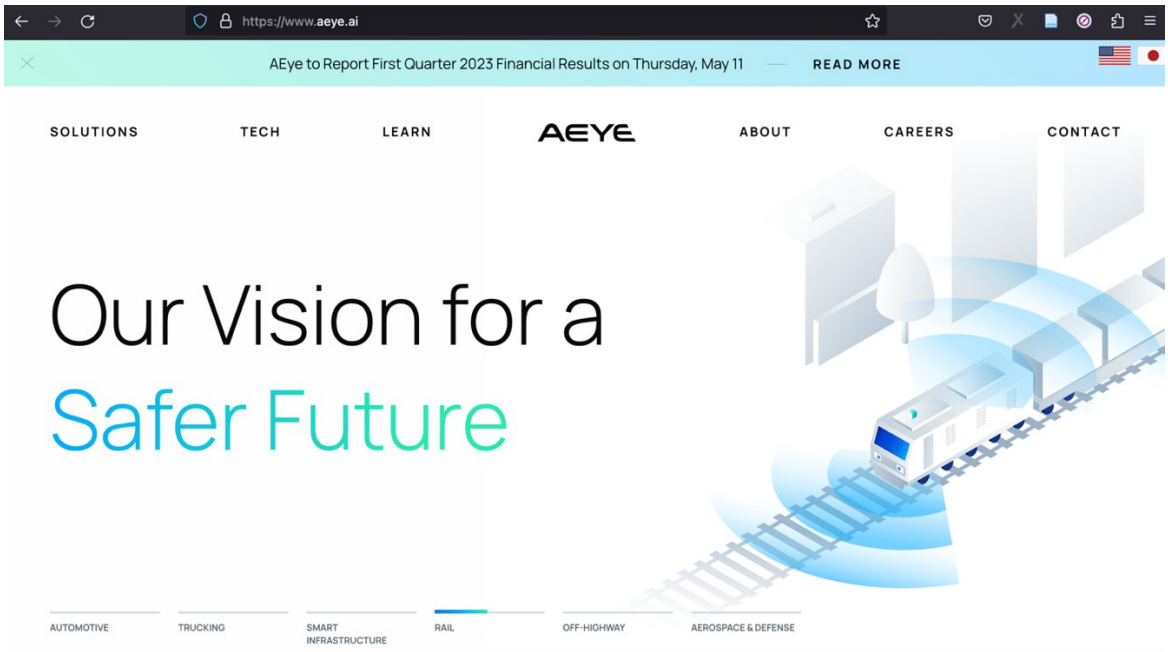


Figure 31 Screenshot taken from AEye's homepage https://www.aeye.ai last accessed 5/6/22.

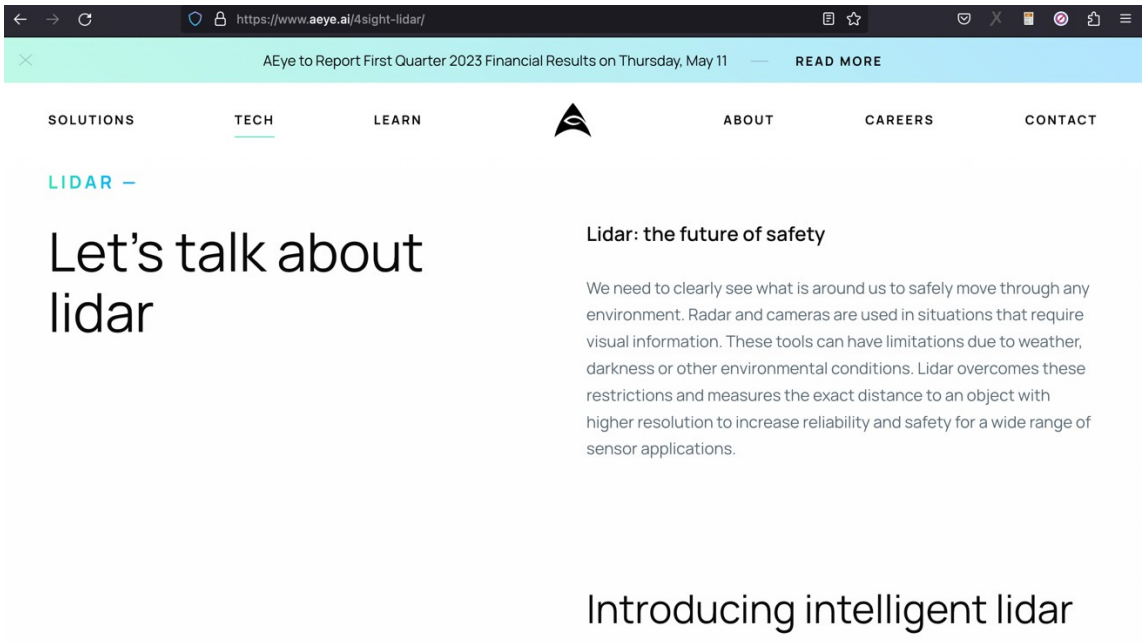


Figure 32 Screenshot taken from AEye's website https://www.aeye.ai/4sight-lidar/ last accessed 5/6/22.

The overall picture, with its biochromatic look (Verity, 1980), communicates a sense of order and sobriety, complementing the overall identity of the brand with its precise and clean presentation of features and explanation of technicalities to support bolder claims. This presentation is repeated for the other applications in which the company is involved.

Here, humans don't matter in their individual identity but only as particles of a larger pattern designed by flows of mobility (see Figure 33).

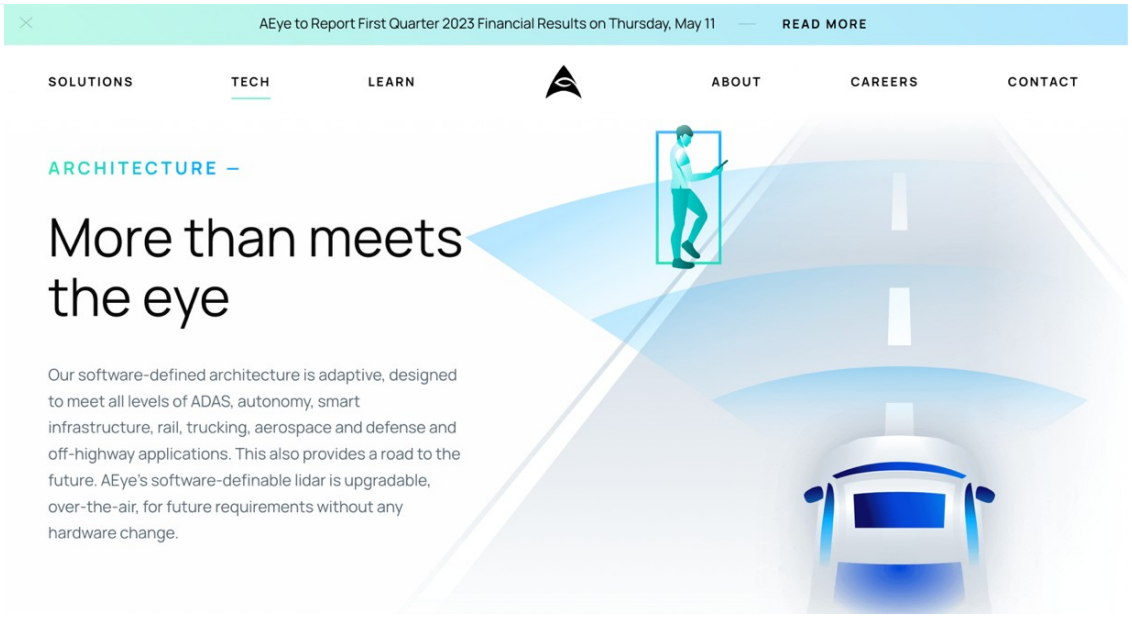


Figure 33 Screenshot taken from AEye's website https://www.aeye.ai/4sight-lidar/ last accessed 5/6/22.

The vector illustration style is consistently maintained. The company highlights their specific vision, a central term we already encountered in the headlines, which is rooted in the power of connection through the technology of smart spaces. Vision through technology is "extended", being infused with the power of communication in and through the surrounding environment. The key words in the paragraphs just before the technical benchmarks that sustain their claims are *efficiency* and *productivity*. The platform is advertised as being adaptive, therefore more capable of imitating the perception of the world as it is performed by a human, with the added benefit of precision. The architecture of the platform can "deliver the future". Clicking on "tech," the page opens with a title reciting "Let's talk about Lidar: Seeing the Future of Safety." "More than meets the eye" is another text just above the presentation of two point clouds presented as "What 4Sight sees: your average intersection seen in a whole new light" (see Figure 34). The image presents a quite granular view of a road ending up at an intersection, a strong vignetting

style, along with some form of interpolation upon the image that gives it the appearance of a ghostly trace of an old slide that came out of a bizarrely advanced but forgotten camera from decades ago. The dominating color is neon blue, leaning towards more deep hues where deeper colors would be in a normal photograph.

Trees and distant traffic lights are dominantly yellow, with spots of deeper orange and red. It's hard to decipher how these colors were chosen, adding to the bizarre, archaic but hyperreal feeling of the image. Another similar artifact is presented. This time the headline says: "Heading down the highway, I've seen much more than you think" (see Figure 35). This image is even more condensed than the other: the pixelated filter is so strong that the shape of a road can be hardly distinguished in the typical neon and blue hues. The lights of the cars near the horizon line appear as red dots. With these couple of point clouds—although it is quite hard to determine how much these images have been interpolated and how much they correspond to what the stack outputs off the rendering layer—the brand intends to support their claims of safety based upon reliability and greater performances that allow for an augmented vision and a better understanding of the environment. But the images proposed end up giving a contradictory feel: the pixelated filter and the vignetted style fail to suggest results that are "future proof" and more precise than human vision.

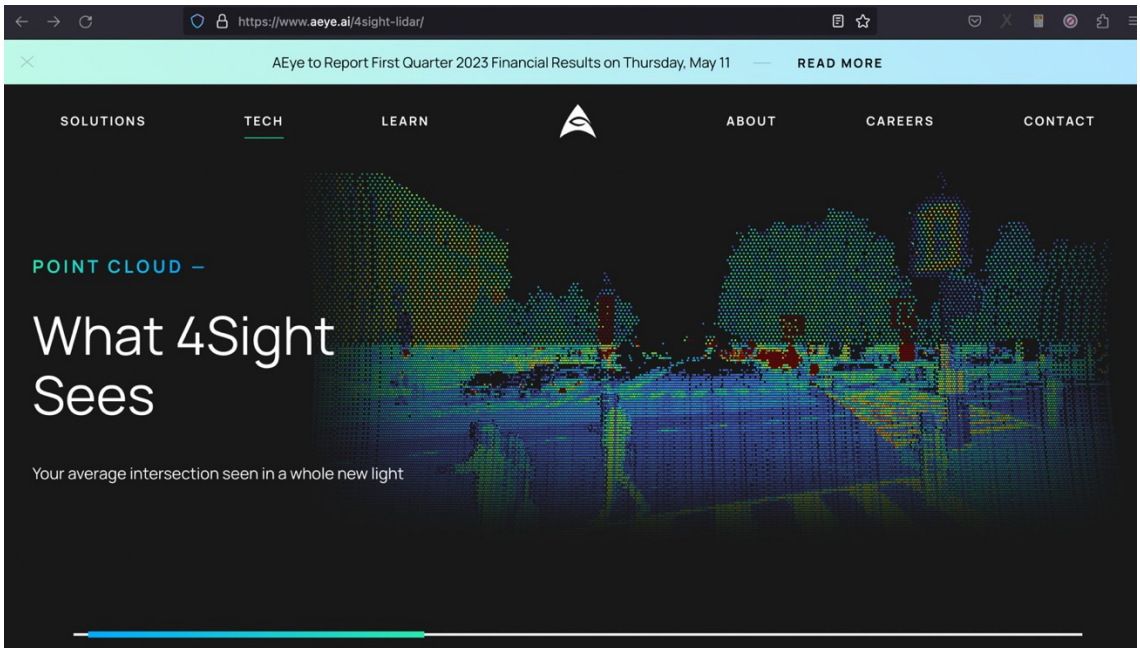


Figure 34 Screenshot taken from AEye's website https://www.aeye.ai/4sight-lidar/ last accessed 5/6/22.

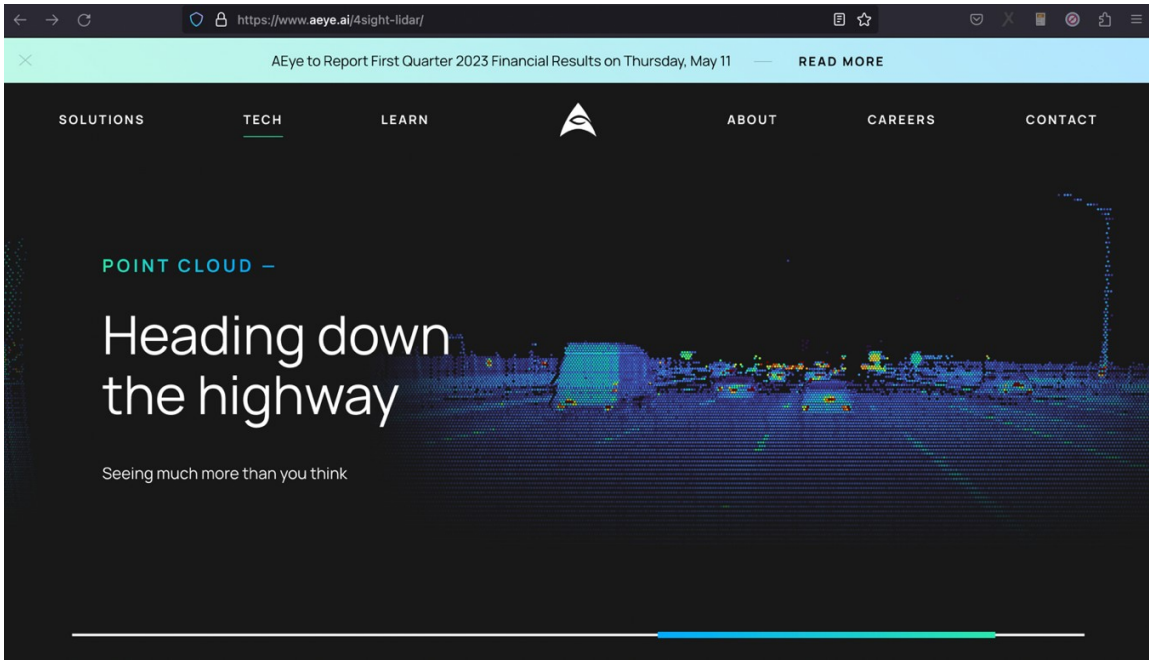


Figure 35 Screenshot taken from AEye's website https://www.aeye.ai/4sight-lidar/ last accessed 5/6/22.

Ouster opts for a colorful and large image, occupying most of the screen space on the homepage. The text sitting on top of it reports the impressive number of partnerships and clients, positioning the brand within a globalist commercial discourse. The image proposed mimics the look of Lidar maps, with colorful neon colors aggressively blocking

out the shapes of a road, a crossing, a couple of indiscernible human figures waiting at the traffic light, and a plethora of luxuriant palms hiding the horizon from the viewer. Magenta, yellow, and blue battle each other to design the edges of the shape of the pavement, the sidewalk, the symbols on the asphalt, and the bag of groceries held by one of the human shapes on the side. It's hard to discern the logic by which colors are blocking out different volumes and edges, but clearly this image has been highly manipulated to be shown to the public, since the usual points and lines constituting a point cloud have been replaced by little squares, almost looking like magnified pixels (see Figure 37).

The company focuses on enlisting their major partner in the automotive supply chain, with pictures of industrial vehicles mounting their sensors. After that, a section with a link invites the viewer to watch a video that illustrates the mission of the brand. The video presents a classic alternate montage with scenes from a car running inside a tunnel, a point cloud zoomed in accordance to the rhythm of the upbeat soundtrack that accompanies the images, followed by a screen with a different kind of point cloud and strings of code running down the display.

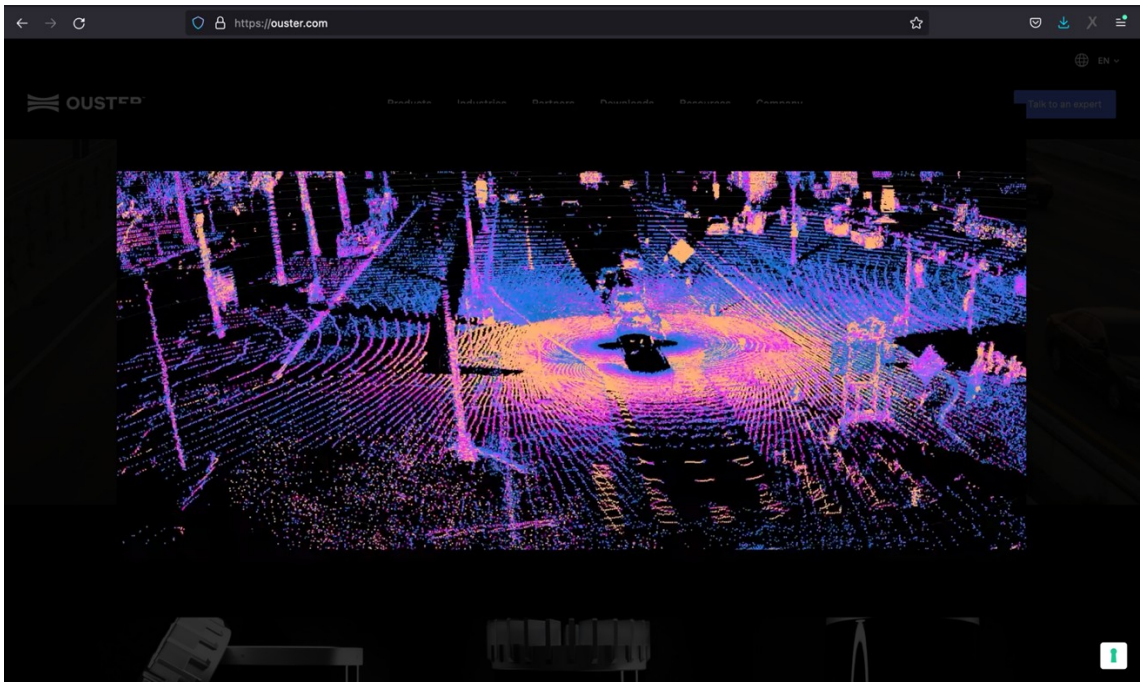


Figure 36 Screenshot taken from Ouster's homepage https://ouster.com last accessed 8/6/22.

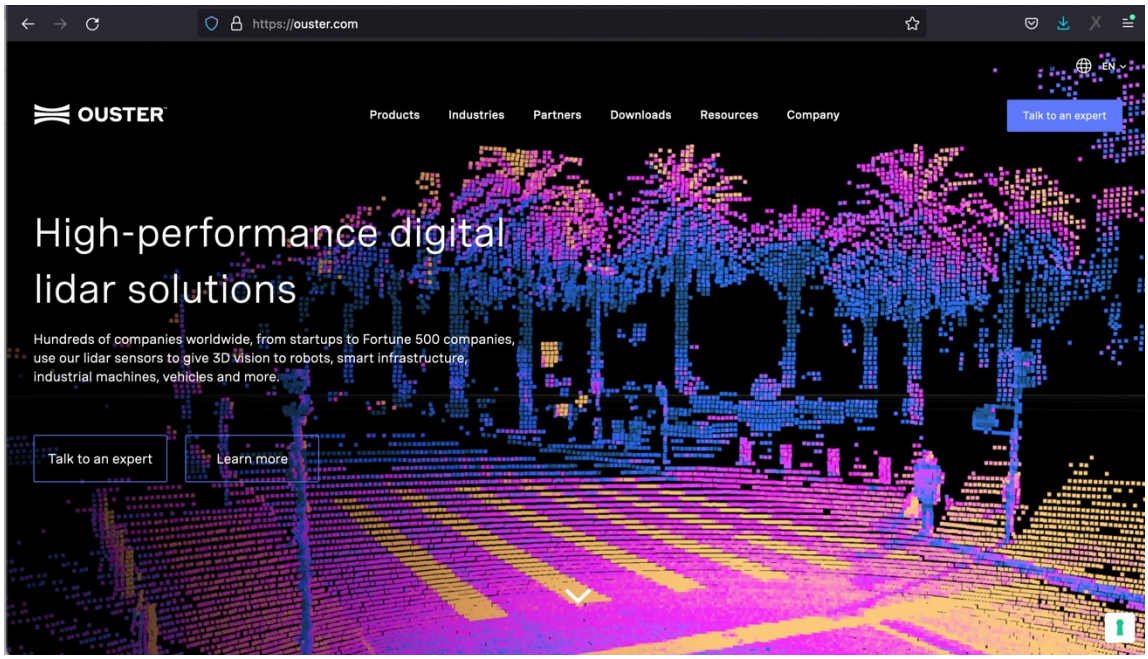


Figure 37 Screenshot taken from Ouster's homepage https://ouster.com last accessed 8/6/22.

The CEO of the company makes his appearance on the screen, stating how the company has a global reach when it comes to automating all sorts of fields in the industrial sector and in logistics. For each application of their product, we see a visual example. Then, the fusion with Sense Photonics is introduced. The ex-CEO of Sense Photonics, now

president of the company, describes their work when it comes to chips in the past years, before the acquisition. While she explains, engineers working in labs with their microscopes and white coats appear on the screen. The woman explains in detail their work, which is based on a move towards digital Lidar, eliminating therefore all moving parts from the sensor—all traces of analogic technology. She quickly mentions the specific type of laser emitters the company employs. Getting back to the homepage, another link sends you to an older video illustrating the mission of the company. In this video, already-seen images of point clouds exercising their auratic power in different settings are shown once again. The CEO explains how the *disruption* created by their digital Lidar will be granted by its affordability, allowing it the power to become ubiquitous and implementable in innumerable different applications in everyday life. The aim of the company is to build "a more convenient, safer world", where we will be "more productive". The discourse doesn't stop at this typical statement in the field; it goes beyond: "You'll be able to sleep in your car and you'll be safe because there are Lidar sensors that are measuring the world all around you billions of times per second". From this statement, the spin the company is adding to the idea of safety is much more geared towards *security*, a position further sustained by their specific page on applications in smarter infrastructure, where Lidar is appointed as the tech that will make it possible to detect intruders and incidents and come up with better solutions for the future.

Overall the company heavily relies on visual exhibitions of the power and precision of their sensor, showing a great number of point clouds, either in video or still images. In fact, in the pages dedicated to the three different sensors they offer on the market, each feature is illustrated by a point cloud. These images are very different from the ones on the front page. They show the same range of colors, but it's clear that the different hues are there to represent relative distances from the sensing object. Moreover, they don't show the pixelating filter that clearly appears on the large image on the homepage. Point clouds

are displayed both for mainly informational reasons and as an overall digital aesthetic that is coherent with the product proposed on the market. This is further sustained by the fact that they offer a whole suite of software and one of their datasets to be explored in autonomy by the viewer.

The remaining three companies put at the forefront of their visual branding the idea of Revolution. Revolution relates to financial disruption as well as a radical change necessary in the overall infrastructure to bring forth the connected and automated city of the future.

"Perception for everything" is the Aeva trademarked motto, putting a different spin on the conjunction between the categories of vision and universality (see Figure 38 and 39).

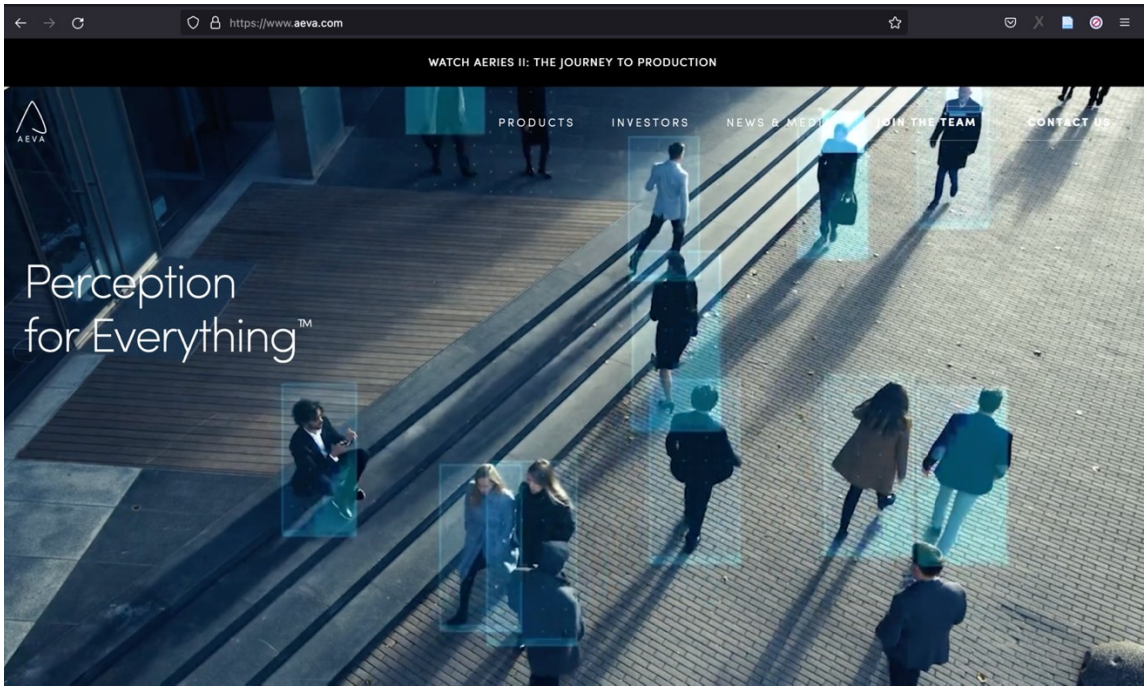


Figure 38 Screenshot taken from Aeva's homepage https://www.aeva.com last accessed 1/6/22.

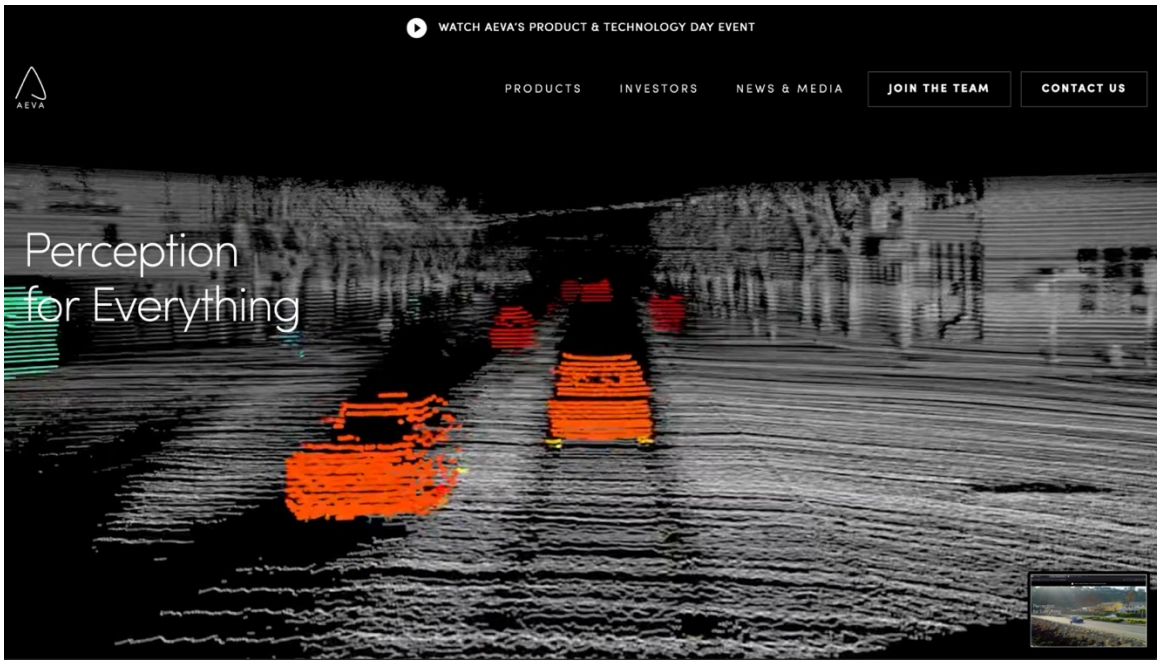


Figure 39 Screenshot taken from Aeva's homepage https://www.aeva.com last accessed 1/6/22.

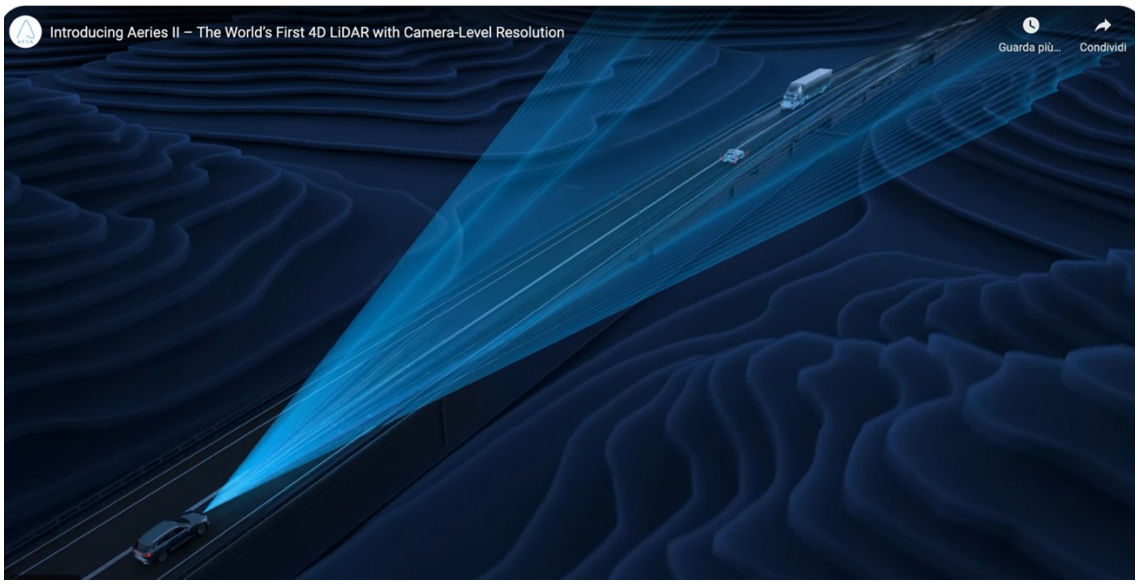
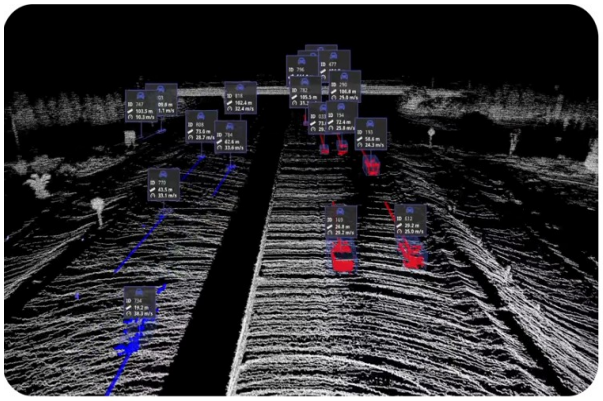


Figure 40 Screenshot taken from a video embedded in Aeva's website https://www.aeva.com/aeries-ii/ last accessed 1/6/22.



Object Detection & Classification

High Confidence Detection, Classification, & Tracking

Instant velocity data allows for high confidence detection and tracking of dynamic objects of concern, such as oncoming vehicles and pedestrians, at distances up to 500 meters.

Figure 41 Screenshot taken from Aeva's website https://www.aeva.com/aeries-ii/ last accessed 1/6/22.

4D Localization™

Vehicle Motion Estimation & Navigation

Per point velocity data enables real-time ego vehicle motion estimation with six degrees of freedom and enables accurate vehicle positioning and navigation in GPS denied and featureless environments without additional sensors, like IMU or GPS.

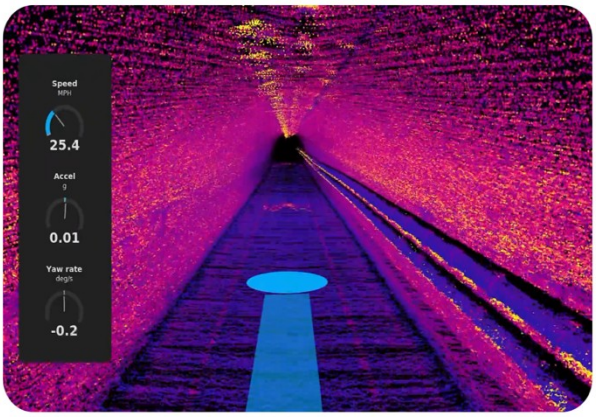


Figure 42 Screenshot taken from Aeva's website https://www.aeva.com/aeries-ii/ last accessed 1/6/22.

Superior Hazard Detection

Identify Small Objects with Greater Confidence

Detect small objects on the road, including low reflectivity objects like tire fragments, at up to twice the distance of legacy time of flight LiDAR sensors.

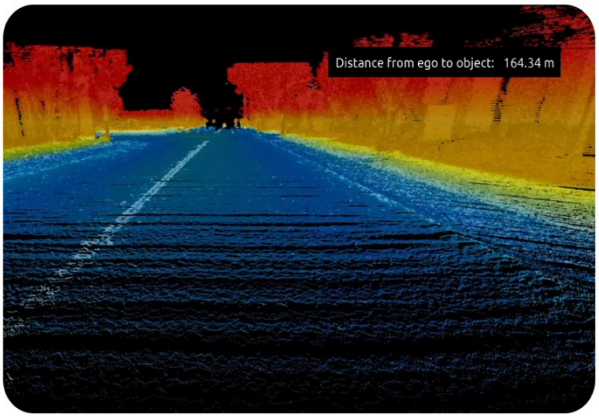


Figure 43 Screenshot taken from Aeva's website https://www.aeva.com/aeries-ii/ last accessed 1/6/22.

Here vision indicates that every environment can be seen through Lidar sensing and therefore mapped and navigated. The idea sustaining universality here is akin to the one sustaining platforms' conceptualization: elaborating a template that can be applied to every place to extract desired effects. Moreover, the focus is dislocated inside the machinic object, depicted as a fully sensing entity. Universality here means that every object can potentially see and therefore locate itself and communicate with other objects. The first point cloud shows a highway; the cars in the distance appear as an orange compound of horizontal lines. And in the following shot, the same scenery is colored in bright hues: deep blue, magenta and red. A young man sits on the stairs of a building to check his phone. Everyone is trapped inside the delicate, pale blue lines of a semantic box. Next to it, two different animated GIFs of point clouds, very similar to the ones shown in the cinematic opening video, illustrate the different layers of elaboration of point clouds. The different coloring is used to indicate different features of the data captured: the neon-colored ones show reflectivity (and therefore distance), whereas the grayscale ones with the red objects show velocity of objects (see Figure 41, 42 and 43).

A video on the page dedicated to their technology shows the chip as it is almost magically infused inside the sensor, and it appears to be ensnared in the white lines slowly forming from simple vectors composing the rendering of a car. The car speeds through a digital road; all is tinged with a deep blue hue (see Figure 40). While the voice describes the functioning of Lidar and how it can be positioned on the car, bright pale blue beams come out of the car, investing everything on the road with their light. The vertical gaze allows the viewer to appreciate the digital landscape the car is setting out to explore, where the hills around the road are designed as topological altitudes. This is an example of depicting a vision of Lidar sensing, rather than showing the end product of the sensor's

algorithmic work. On top of that, confusions between subject and object appears more strongly – a theme that will be further explored in Chapter Six and Seven.

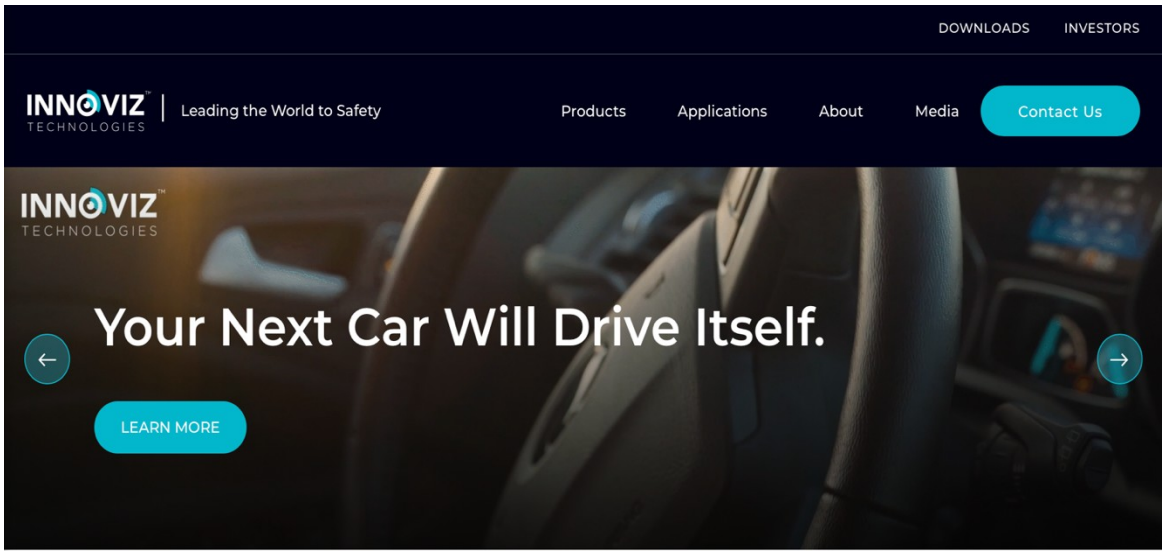


Figure 44 Screenshot taken from Innoviz's website https://innoviz.tech last accessed 25/6/22.

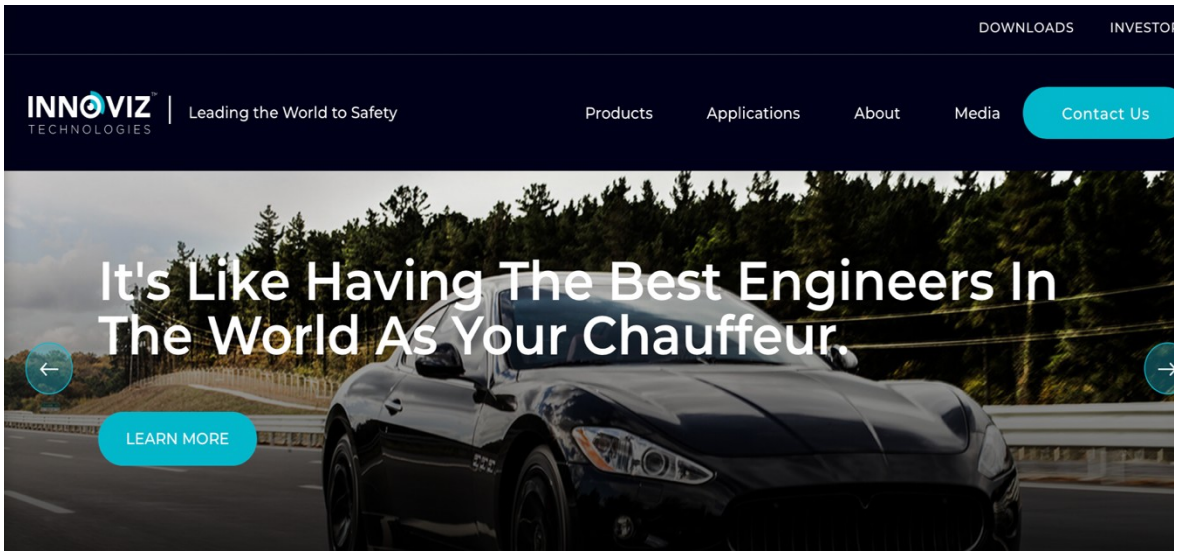


Figure 45 Screenshot taken from Innoviz's homepage https://innoviz.tech last accessed 25/6/22.

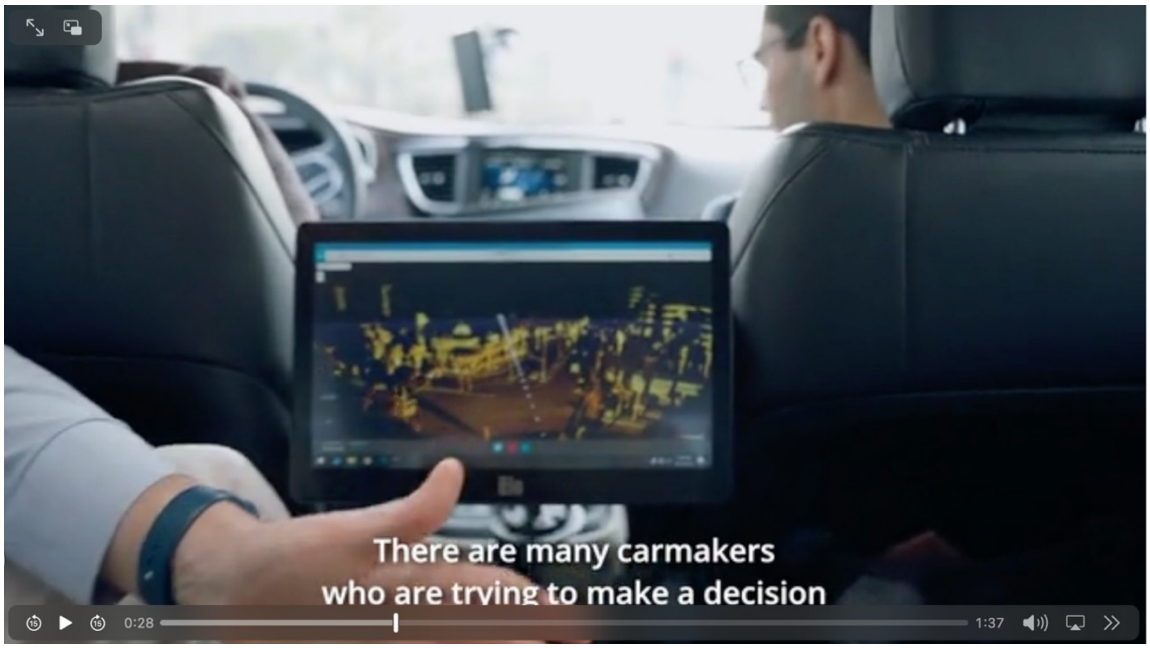


Figure 46 Screenshot taken from a video embedded in Innoviz's website https://innoviz.tech last accessed 25/6/22.

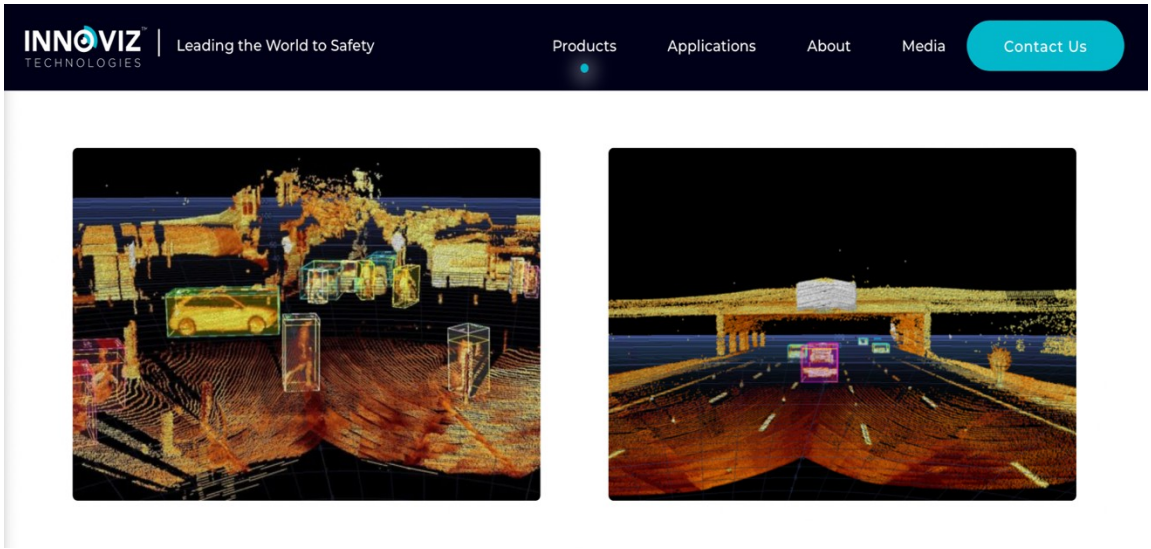


Figure 47 Screenshot taken from Innoviz's websit https://innoviz.tech/perception-software last accessed 25/6/22.

Innoviz's heading recites "Leading the World to Safety." Immediately under the header and the links to the other pages, there is a slideshow showing pictures of cars, roads, and a wheel. Each photograph is accompanied by humorous white writing just on top. One of them states: "It's like having the best engineers in the world as your chauffeur" (see Figure

45). Just below the main statement of the company is the statement that their product is already available for fully scalable mass production. The video alongside the paragraph explaining this as their main strength shows the CEO of the company boarding a branded car ready for testing around Tel Aviv. Once onboard the vehicle, while the head of the business sits in the back of the car directly talking to the camera and explaining the story of their company, two engineers sit on the forefront of the vehicle with a big screen among them showing a point cloud, producing an interesting effect of *myse en abyme*, or, in other words, of a film within a film, where the film is a digital copy of the reality being recorded and heavily edited to be reproduced as a film (see Figure 46). Apart from this instance, the company doesn't seem to rely heavily on point cloud exhibitions, which are relegated to the last page of the subsection of "products." Here, point clouds of very specific objects incorporated in their semantic box are shown in a sort of collage: a person walking, a car, a bicycle, a motorcycle, and a truck (see Figure 47). This is a rather unusual scale of presentation; usually, showing a large field of view is preferred. Nonetheless, this brand doesn't rely heavily on point clouds as their main visual strength, preferring numbers highlighting their performances and pictures of actual cars. Nonetheless, the heavy insistence on performance is connected to the main statement that a revolution in mobility is already possible, and this is backed by performance numbers and benchmarks.

The strongest visual impression is provided by Luminar. The homepage of the American company welcomes the viewer with an interactive GIF that occupies most of the screen space. Moving the mouse across the screen, an incredibly colorful point cloud moves around, changing point of view. A stark white, bold inscription recites "We've seen the future of transportation because we've built it" (see Figure 48). The moving image shows the shapes of a big intersection with passing cars and a traffic light. The ever-changing bird-eye view offers to the gaze the landscape behind: what seems to be a great square,

enclosed by a giant classic building. It's impossible to determine its exact architectural style or even its function just by looking at the bright neon colors that paint it against the black backdrop. Shapes of trees fill the corner of the view, while other buildings in different styles seem to emerge behind them. The predominant colors are: deep blue, magenta, red, orange, yellow, and pale blue. They envelope the shape made of continuous lines and scattered points one after the other, gracefully merging on the planes. Other surfaces present starker blocking, it's hard to extract a logic by which each color stands where it is.

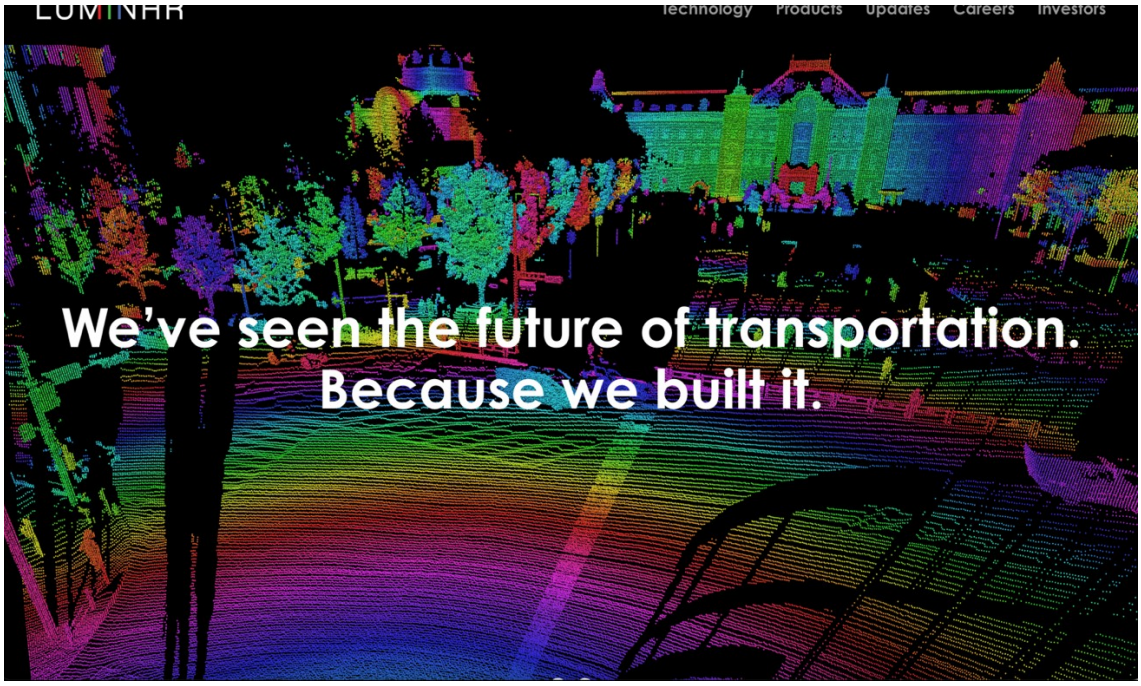


Figure 48 Screenshot taken from Luminar's homepage https://www.luminartech.com last accessed 29/4/22.

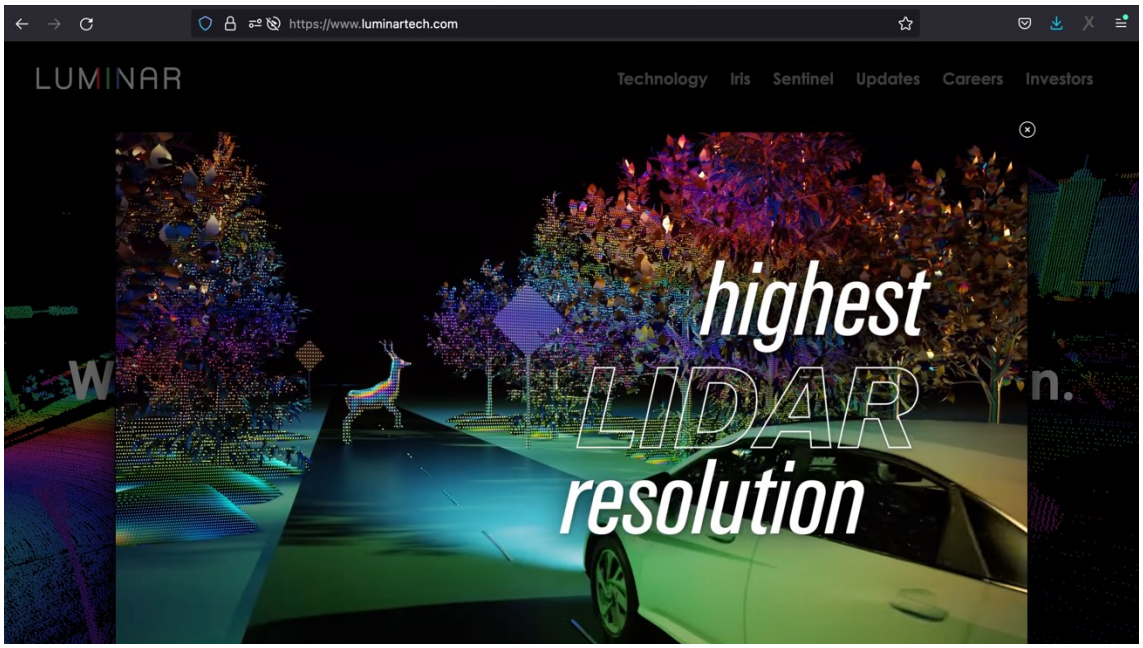


Figure 49 Screenshot taken from a video embedded in Luminar's website https://www.luminartech.com *last accessed 29/4/22.*

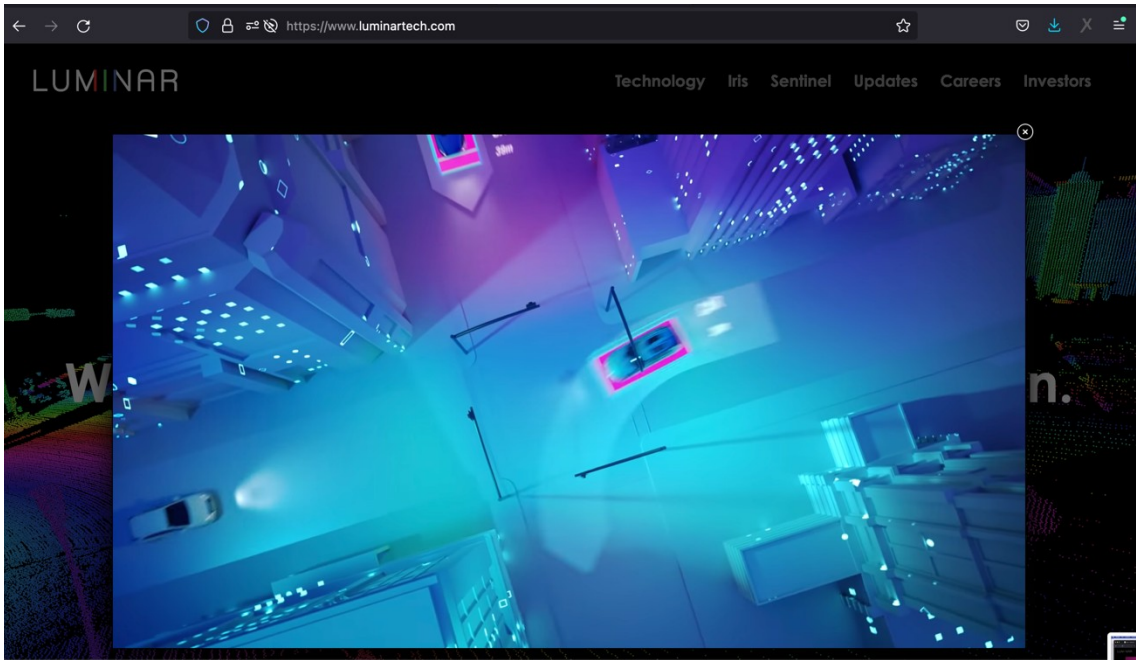


Figure 50 Another screenshot from the same video by Luminar https://www.luminartech.com *last accessed 29/4/22.*

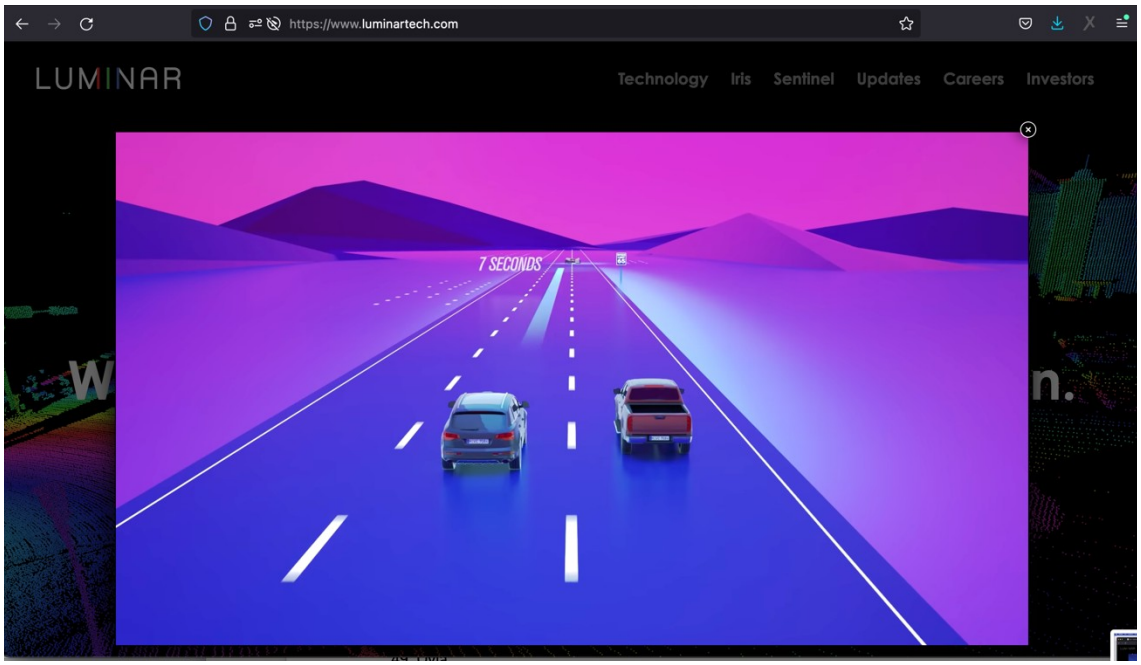


Figure 51 Again another screenshot from the same video from Luminar https://www.luminartech.com last accessed 29/4/22.

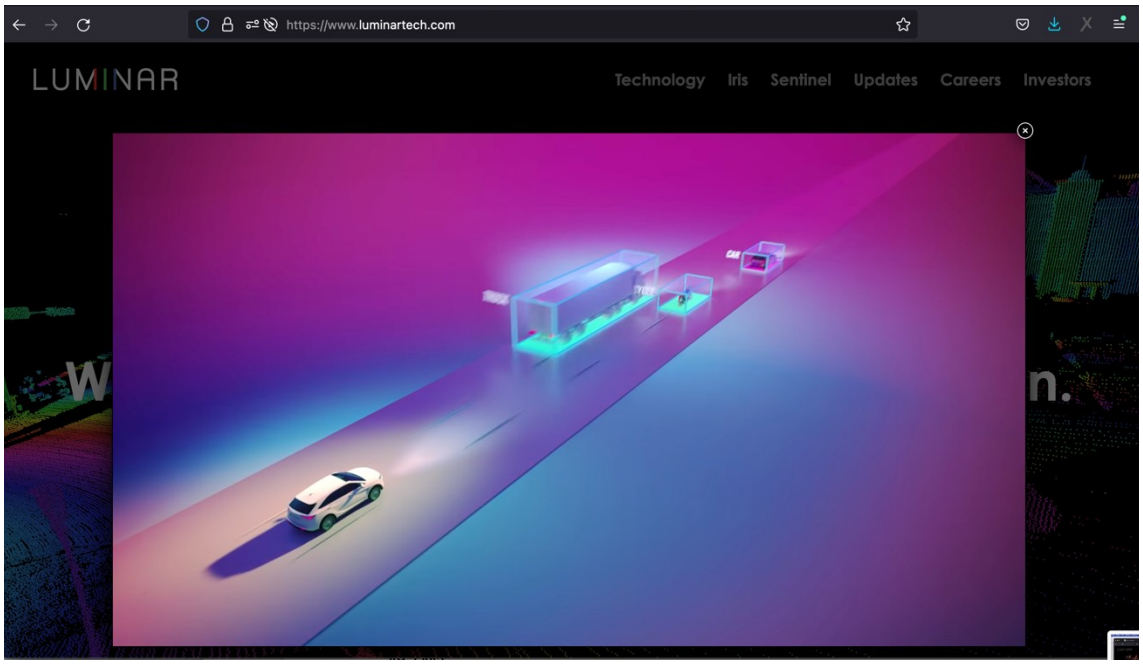


Figure 52 Another screenshot from Luminar's video https://www.luminartech.com last accessed 29/4/22.

In the homepage, the main video embedded shows an animation depicting a car working in various settings. No point-cloud is present here, rather a starkly vaporwave (Cole, 2020) choice of colors shows the car immersed in blue and magenta roads, in the city or in a rural environment (see Figure 49, 50, 51, 52). This aesthetic choice puts a nostalgic and

juvenile spin on the idea of a future that is already present, and already possibly lost, with the pixelated deer about to disappear in front of the 3D rendering of the car. The white header declares: "We see the world differently". The technology page offers a different rendition of this vision. A haunting animation starts with a semantic box in a soft green hue with some numbers on top of it (see Figure 53).

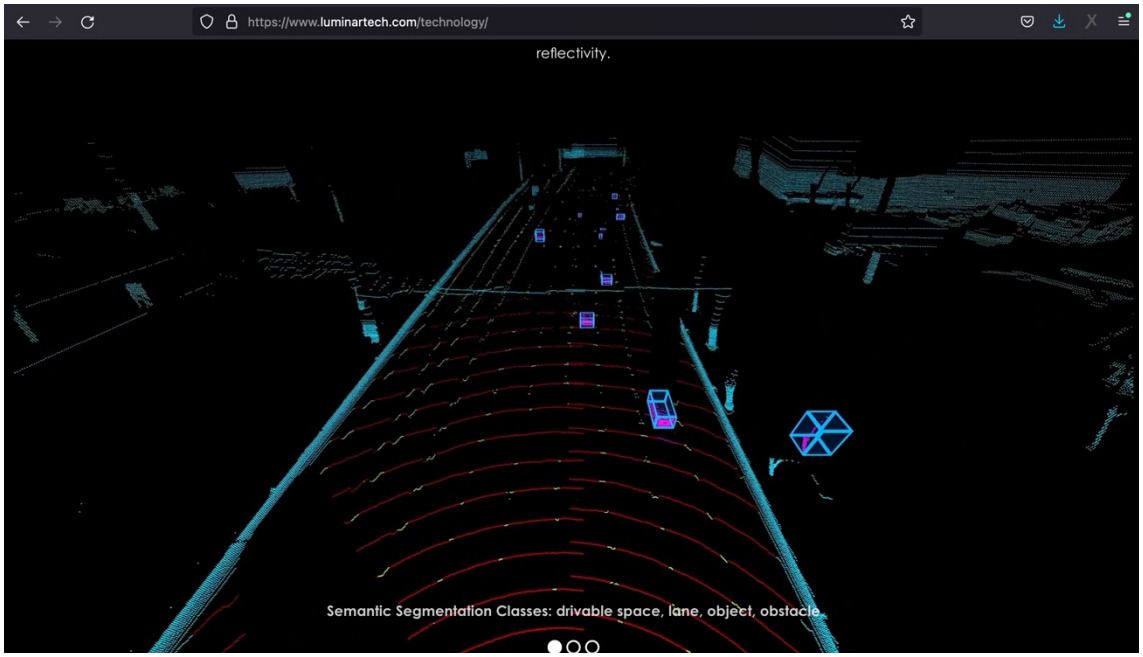


Figure 53 A screenshot from an animation in Luminar's website https://www.luminartech.com/technology last accessed 29/4/22.

A hazardous zoom out shows how that classified object is only one of many. The point of view shifts towards an almost vertical vantage point, revealing a four-lane highway, the pavement filled with the usual graphic look of point clouds. In this image, the neon colors seem to be distributed to depict distance. Nonetheless, the image at the peak of its height fades to black, almost as if the drone taking the shot lost itself in the clouds. A brief paragraph explains how the ability to see at long distances allows for safe reactions even at higher velocities. Their classification method is explained with bird-eye view shots and vertical ones to prove the distance between the objects being detected. Luminar relies heavily on their visual branding, with a minimal and rather simple-to-understand textual

counterpart. Given their flashy header on the homepage, it seems like the company is trying to establish that the future has already been reached and somewhat lost through their masterly blend of vision and intelligence, that currently has got no peers in reality.

5.5 Conclusion

All eight companies comprised in the sample for this analysis showed the presence on their websites of visual strategies to sustain their branding, utilizing different combinations of the eight categories—safety, time, performance, vision, intelligence, universality, and revolution—buried within the display of either point clouds or simulation videos. Seven of them exhibit point clouds to sustain their claims and illustrate the strength of their product; nonetheless, the prominence given to them varies in degree according to the hierarchical schema provided in the previous chapter. It's important to note, also, that point clouds are shown through different media (stills, animated gifs, interactive flash, video, and video in video). Moreover, they are accompanied by different textual or speech aids to help shape their meaning. Two companies, Luminar and Ouster, rely heavily on visual branding; this is evident by the great amount of screen space they devote on the homepage to a form of interpolated point cloud that becomes a pure aesthetic ornament. AEye, instead, doesn't show any point clouds except for a highly interpolated one on a secondary page. Pony.ai doesn't show any point clouds, favoring the end user's visualization of the car perceiving the road. Nonetheless, it presents the most compact discourse around the deployment of Lidar imaging in the making of the driverless car.

This discourse usually entails a simplified version of how Lidar works within the larger perception system. Lidar is described as the discriminant sensor within a larger compound

made of cameras, radar, and GPS, allowing for real-time mapping, that is reliable and, thus, safe. The data mined on site from the sensors composing the perception stack is fused together with a Kalman filter[16] and used by software, generally machine learning, to distinguish objects—be the other vehicles, bicycles, trucks, landmark features, or pedestrians—with a process of semantic segmentation that applies moving boxes to them. This passage constitutes the control system that then allows the car to make informed decisions regarding how to proceed or stop in the face of obstacles.

All the companies present different views of the urban landscape: iconic sites, busy streets blooming with life, highways, intersections, and parking lots. When the city is presented in cinematic shoots, we are mostly presented with suburban landscapes, a slower pace of life, and visions of the moving landscape through a window (Terranova, 2014).

All the companies, through a modular combination of the different categories, seek to present their product as revolutionary, disruptive, safe, and secure while producing different spatialities, augmented through digital perception, and inscribed within temporalities that highlight velocity and speed, and a claim to the future of the city and beyond. The city of the future is inevitably intelligent, infused with cutting-edge technology, as the benchmark shows through the incontestable power of numbers, and

[16] A Kalman filter is an algorithm used for estimating the state of a system from a series of noisy measurements over time. It was developed by Rudolf Kalman in the 1960s and has since found widespread application in various fields, including sensor fusion (Kalman, 1960).
In sensor fusion, Kalman filters play a crucial role in combining data from multiple sensors to improve the accuracy and reliability of the estimated state of a system. This process is essential in many applications, such as navigation systems, robotics, and autonomous vehicles (Li et al., 2015).
The Kalman filter works by predicting the current state of the system based on its previous state and a model of how the system evolves over time. It then incorporates new measurements from sensors to update the state estimate, taking into account the uncertainty associated with both the predictions and the measurements. By iteratively repeating this prediction-update process, the Kalman filter continually refines its estimate of the system's state, providing a reliable and accurate representation even in the presence of noise and uncertainty (Kim and Bang, 2018). In simpler terms, the Kalman filter enables systems which collect data from multiple sources to combine information effectively.

universal. Its technical solutions can be applied everywhere to ensure smooth and secure flow. Such claims are common to the data imaginary (Beer, 2018) and problematic for the reasons described in the introduction of this chapter. However, the inner grammar of the normative power of these geovisualizations will be further analyzed and described in the following chapters.

Movement in Lidar imaging

6.1 Introduction

In line with the established framework in critical cartography, the preceding chapters have highlighted how the integration of Lidar imaging on commercial websites primarily serves to leverage its digital aura, elevating the futuristic positioning of technology companies within the realm of advancing the world through an array of sensory and intelligent technologies.

Specifically, in Chapter Five, following multimodal discourse analysis, I have elucidated, through simplifying key concepts, how images are strategically employed to perpetuate a specific rhetoric that establishes the appeal of Lidar technology and, by extension, automation within the city of the future. Although the materials under scrutiny in this analysis differ significantly from those examined in prior studies, where textual analysis took precedence over visual tropes, in this thesis, I have chosen to adopt an alternative perspective. While I concur with the notion that the discourse surrounding data analytics extends beyond mere rhetorical marketing tactics, I contend that, in accordance with the insights from previous chapters, by exploring the limits of discourse itself, intriguing aspects of the interplay between imagination, visuality, and visual perception can be uncovered.

In other words, drawing from concepts delineated in Chapter Two of the present thesis, in *Techniques of the Observer* (1992), Crary explores how computer-mediated vision transforms our perception of the world and ourselves. He takes a historical approach, tracing the evolution of vision and perception, emphasizing the continuous nature of these changes rather than seeking a complete history. Crary challenges the notion that

modernist art represents a rupture from Renaissance-era vision, arguing that both are interconnected. He also discusses the impact of photography on spatial perception.

Crary highlights how optical toys like stereoscopes and phenakistiscopes in the 19th century are linked to shifts in social power and the reconfiguration of the body's relationship with visual knowledge. He draws on Foucault's insights about population management and the creation of norms and normality, which made "the subject" visible. This visibility is aimed at quantifying and controlling individuals and their vision.

Crary suggests that Foucault's work didn't fully explore how vision itself became a form of discipline. In contrast, David Beer's study (2018) focuses on the data analytics gaze but overlooks the disciplining aspects of vision, concentrating more on textual analysis and how it constructs and produces social imaginaries.

In this chapter, I aim to conduct a filmic analysis of Lidar imaging in its video format. This endeavor seeks to fill the void left by Beer's emphasis on textual discourse in constructing the imaginary and Crary's preference for delving into past technologies, with only passing mention of computer-augmented approaches to perception management and spatial organization. My objective is to have Lidar imaging communicate its unique way of capturing reality, manipulating time, and offering glimpses into computational and visual processes.

To achieve this, I intend to liberate Lidar's visual language from the confines of commercial discourse, which have been categorized in their constituting parts in the previous chapter, and analyze its visual structure. In the first section of this chapter, I will be reporting about the experience provided by the Aspen Movie Map (1978-1981), which we encountered in the first chapter as a precursor to Google Street View and, consequently, to Lidar sensing, seen here as a tool that has cognitive effects (Ihde and

Selinger, 2004; Magnusson, 2009). Following that, drawing from Wilson's analysis (2017), I will provide a brief overview of his selected genealogy of animated cartography.

Following this, I will probe further into the history of animation in cartography, reaching back to its earliest experimental phases that predate the computer era. Drawing inspiration from the insights of animation and film theorists, I will then proceed to conduct a comprehensive analysis of the selected videos. This analysis will be informed by the techniques and principles uncovered throughout the genealogy of animation and animated cartography. Finally, I will conclude the chapter by providing a concise summary of my findings.

In this manner, I aim to establish a theoretical foundation for critically analyzing the formal elements that constitute the presentation of Lidar imaging in video format, which conveys a continuous data stream modeling the environment. In the context of the specialized market under examination, this pertains specifically to urban sites.

6.2 Google Street View ancestry: the Aspen Movie Map

Google Street View can be considered an early precursor to Lidar imaging due to its ability to provide a three-dimensional representation of the environment. In this regard, Google Street View, which has been in operation since 2010, can be seen as a pioneering force in the realm of digital mapping. Both Google Street View and Lidar imaging serve the purpose of creating 3D maps of the environment, although they employ different technologies. Google Street View relies on 360-degree cameras to capture street-level imagery, while Lidar imaging utilizes laser scanners to gather intricate 3D data about the surroundings.

Integration with Geographic Information Systems (GIS) is a common feature shared by both Google Street View and Lidar imaging, allowing for in-depth analysis and interpretation. Over time, Google Street View has become more customizable, permitting the inclusion of components such as Lidar to capture more detailed imagery[17]. Similarly, Lidar imaging can be tailored to capture specific types of data, including surface volumes, textures, and even textual representations, making its outputs increasingly resemble those of traditional cameras.

While Google Street View and Lidar imaging exhibit distinct technological characteristics, they also share certain commonalities, such as their application in 3D mapping, compatibility with GIS systems, and adaptability for specific purposes. Beyond these technical aspects, both technologies have the capacity to influence the management of place and space, impact research endeavors, and inform technological design to enhance user experiences. Furthermore, they raise important ethical, privacy, and surveillance considerations, which will be explored in subsequent chapters.

In Chapter Four of this thesis, we have seen how Gilge (2016) provides a critical analysis of the impact of Google Street View on our perception of the built environment and our experiences in spatial navigation. The author traces the historical roots of Google Street View back to an earlier experiment known as the "movie map" of Aspen, which was developed and researched by MIT's Architecture Machine Group between 1978 and 1981. A detailed account of this experiment can be found in Mohl's Ph.D. thesis from 1980, where he elucidates the research objectives, development process, experimentation, and potential applications of this innovation.

[17] https://blog.google/products/maps/street-view-15-new-features/ Last accessed 14 September 2023.

The "movie map" was essentially a map that replicated the environment, allowing users to engage in "surrogate travel" and enhance their geographical knowledge in ways that conventional static maps could not achieve (Mohl, 1980:1-5)[18]. Initially funded by DARPA for military research purposes, the experiment aimed to improve orientation in unfamiliar environments by understanding how humans construct "cognitive maps" for practical purposes (Mohl, 1980:103-118). Mohl's thesis provides detailed insights into the meticulous work required to capture over 50,000 usable frames of Aspen for mounting on a videodisc (Mohl, 1980:8-85).

The moving map also featured a navigational two-dimensional map that users could access to aid their orientation in the recreated three-dimensional space. This moving map incorporated temporal features, allowing users to choose the season in which they virtually explored the city and access multimedia files explaining the cultural significance of specific locations. The experimentation yielded valuable insights into virtual space and time, particularly the concept of "durability" as applied by users to navigate the space, with different entities in virtual space representing events with varying degrees of durability (Mohl, 1980:87-102). For instance, a building had long durability, whereas a passing horse-drawn carriage represented an event with very brief durability.

The thesis also delved into problem-solving strategies, including effective filming of roundabouts and intersections for accurate representation. Additionally, it explored the use of computer graphics to simplify external features on maps, making them more easily readable (Mohl, 1980:23-30).

[18]Mohl references the work of Lynch (1960) as a predecessor in the intentions and aims of the research. But, while Lynch used “anecdotal data”, Mohl’s mission is to obtain a degree of objectivity. Interestingly, this idea of creating an “image of the city” for functional purposes is till used in the department of Architecture of MIT – cfr. Ho’s 2018 Thesis.

Mohl's thesis provides the most comprehensive account of the creation of a "movie map" of Aspen. However, scholars have highlighted that this project, which was undertaken within the Architecture Machine Group at MIT, was the result of complex teamwork involving engineers, technologists, and artists who were exploring new digital technologies. The role of artists within the application of computer graphics to digital mapping was distinctive, and figures like Negroponte and Rebecca Allen subsequently pursued their work in innovative directions with different political implications than the original project (Hoth, 2021). Nevertheless, as Halpern's analysis of the original project documents reveals, the overarching new ontology and epistemology developed within the project remained remarkably cohesive (2015, pp. 118-120).

Upon reading Mohl's original text, it becomes evident that, apart from the project's evident military applications, as reflected in its funding and reiterated in the thesis, it offers a seminal taxonomy of time and space in the context of the relationship between the physical world and its digital representation—a framework that continues to be relevant today (Mann et al., 2018).

The Aspen Movie Map and Lidar imaging, despite being distinct technologies, share intriguing parallels. One notable commonality is their capacity for three-dimensional mapping. The Aspen Movie Map created a three-dimensional polygonal model of a city, allowing users to virtually explore its environment. Similarly, Lidar imaging excels at producing highly detailed three-dimensional datasets, offering precision in capturing terrain, vegetation, and physical features with remarkable accuracy.

Texture mapping is another feature they have in common. The Aspen Movie Map employed three-dimensional texture mapping to realistically represent landmark building facades. In a similar vein, Lidar imaging can capture intricate surface textures of objects and terrain, enhancing the visual fidelity of its representations.

Both technologies also enable the mapping of physical features with great precision. The Aspen Movie Map facilitated virtual tours, providing users with a digital representation of the physical world. Lidar imaging, on the other hand, excels at mapping physical features with remarkable resolution, often presenting this information in a dynamic video format.

Additionally, both the Aspen Movie Map and Lidar imaging can be seamlessly integrated into Geographic Information Systems (GIS) for comprehensive analysis and interpretation. This integration is a valuable aspect of their practical utility, as GIS plays a crucial role in planning and decision-making.

Beyond these technical parallels, it's important to acknowledge that the Aspen Movie Map had its origins in the military-academic complex. It was built upon a theoretical and material understanding of temporality and its visualization through movement, which enhanced human cognitive abilities for navigating unfamiliar environments for practical purposes (Ihde and Selinger, 2004; Magnusson 2009). In a seemingly paradoxical manner, the movie map combined a simulation of organic movement through an environment, while allowing the users to visit a specific place as crystallized at a specific time, through data and metadata retrieval. Similarly, a representation of time and space is evident in Lidar imaging videos, often employed for marketing purposes by companies. These videos show Lidar imaging at work, as if it were capturing and outputting a stream of real-time data about the road, or the environment to be modeled. But the videos are

crystalized in time. They offer a montage of previously selected streams of data, to highlight specific features, according to the different kinds of marketing categories preferred by the individual company. This crystallization is disguised through the movement represented in the video. To delve deeper into their formal characteristics, a detailed analysis of the elements of animation becomes indispensable.

However, the fascination with using moving images to explore geography did not originate in the 1980s with Mohl's research on movie maps. At Harvard, the exploration of innovative methods for visualizing spatial data had been a compelling endeavor since the conclusion of World War II.

Thus, in the subsequent section of this chapter, I will provide a concise history of how animation has permeated geography. This historical exploration aims to unearth valuable concepts and practical methodologies for describing movement and elucidating the spatial and temporal dimensions it encompasses. By doing so, we will be better equipped to understand and analyze Lidar imaging and its presentation in video format, thus enhancing our comprehension of this technology's implications.

6.3 Animated Cartography and the moving image

The world of digital mapping has witnessed a remarkable evolution, marked by the convergence of technology and imagination. Within this landscape, animation has emerged as a powerful tool for depicting movement, unraveling spatial intricacies, and visualizing temporal dimensions. Exploring Lidar videos, the product of a technology known for its precision in capturing the physical world, tracing the historical trajectory of animation within geography proves not only insightful but essential.

In this section, I delineate the historical infiltration of animation as a storytelling medium for spatial and temporal phenomena. This historical exploration of how animation has infiltrated the geographical domain is undertaken to unearth theoretical concepts and foreground methodological approaches. By doing so, the aim is to shed light on the significance of this historical evolution and to ultimately comprehend and dissect Lidar videos and their visual tropes, in capturing and portraying the surrounding world.

Through the lens of animation's historical integration into mapping, I will uncover the tools and frameworks necessary to dissect the dance between data and image, space and time, that Lidar videos encapsulate. This historical perspective will not only provide a deeper understanding of the visual rhetoric employed in the presentation of Lidar imaging but also offer fresh insights into the current technology's practical applications (while underscoring how the current trajectory is merely contingent).

Thus, navigating the juncture of animation and geographical representation, it will emerge how the past not only informs the present but also shapes the (possible, imagined) future. The parallels between geospatial moving images and the dynamic world captured by Lidar imaging will become apparent, offering methodological tools to elucidate the intricate relationship between movement, space, and time.

In the work of geographer Wilson (2017), we encounter a meticulous and nuanced exploration of the genealogy behind the convergence of digital technologies and the presentation of geographical knowledge through moving images. This historical journey precedes the emergence of movie maps by several decades and offers profound insights into the development of this field.

At its core, Wilson's research delves into the writings of Walter Isard, an economist and a member of the Regional Science Association, whose influence extended to MIT. Isard's work, grounded in economics, laid the foundation for the discipline of regional analysis, notably through methodologies like input-output analysis (Jackson, 2004). His writings had a profound impact on the field of geography, sowing the seeds for the later evolution of Geographic Information Systems (GIS). One pivotal outcome of Isard's influence was the creation of Harvard's Laboratory of Computer Graphics and Spatial Analysis, where Bill Warntz, also a Regional Science Association member, played a pivotal role in disseminating Isard's ideas.

Wilson draws attention to the intersection between an economist and mathematical geographers, leading to a burgeoning interest in portraying locational processes through moving imagery. This endeavor, according to Wilson, seeks to "freeze time" to allow for an in-depth examination of spatiality (2017:70). Wilson elucidates this notion, explaining that maps historically aimed to decelerate the passage of time, offering a moment of reflection amidst the relentless march of temporal progression.

However, the introduction of Big Data brought about a significant technological shift that complicated the trajectory of moving maps. Wilson observes how, in the era of big data analysis, moving maps depicting the evolution of processes have become a distinct form of digital cartography, particularly prominent in the realm of social media and new forms of journalism (Dodge, 2018). These representations, often sleek and aesthetically curated, resist easy categorization as mere spatiotemporal portrayals.

Drawing from the conceptualization of cinema and the moving image by Deleuze, Wilson investigates moving maps as entities that illuminate our understanding of the intricate interplay between knowledge and power, subject and object, and representation in both traditional and post-representational manners. Wilson accords immense heuristic power to the tools and methodologies associated with digital mapping, reflecting upon their potential to revolutionize the production of geographical knowledge.

Furthermore, Wilson contemplates the emergence of qualitative GIS, which initially promised to offer a novel approach to geographical knowledge but ended up ensnared in representational challenges akin to quantitative GIS. His analytical quest is rooted in excavating the history of animated cartography, aiming to liberate mapmakers from the confines of representational efficacy and encouraging them to engage with their design choices, cognizant of their profound influence on shaping worldviews.

Wilson's project aligns with Don Ihde's conceptualization of data visualization in science, wherein data representations contribute to the construction of our perception of the world (Ihde, 1990; 2003). His genealogy of animated cartography seeks to illuminate the material processes of creating moving maps and the ideas, intentions, and choices that create new conditions for thought and action. These choices, Wilson argues, possess both aesthetic and political dimensions, as they produce images with distinct representational qualities and effects while also reflecting a particular worldview and influencing the dynamics of knowledge and power.

In Deleuze's conceptualization of cinema and the moving image (1985), there lies the idea that cinema has the capacity to open a portal into the intricate layers, convergences, and departures of forces that interact within the world. It achieves this by making visible

the interconnectedness of all that exists within the universe, revealing the dynamic interplay between what exists and the signs that express it. Deleuze's theory of the moving image seeks to describe a metaphysical space that has the potential to evade the constraints of language.

Wilson, building on Deleuze's insights, introduces the concept of "determinant indeterminacy" (p. 73) to describe this interstitial zone. He argues that while the moving map is the result of technical and design processes guided by creativity and intention, the outcome cannot be fully encapsulated by analyzing its individual elements. There exists an aesthetic effect produced by the whole that defies complete verbal description. This characterization resonates with post-representational discussions of geo-visualizations found in the literature. For instance, while other scholars often focus on the characteristics depicted within the images (Bissel and Fuller, 2017) or consider their effects on viewers (Aitken and Craine, 2009; Craine and Aitken, 2011; Newell and Canessa, 2015), Wilson concentrates on the formal elements that constitute the image's movement—how movement is technically constructed within the moving map and what kind of worldview is inscribed within this movement itself. This approach seeks to unveil affective effects that transcend mere representational efficacy.

Wilson's quest for continuities rather than ruptures between two instances of moving maps, despite over 50 years of technological development separating them, exemplifies his approach. He examines the 1967 movie map of Lansing, titled "Urban Growth Dynamics 1850-1965", created by Allan Schmidt's team at the University of Michigan (see Figure 54 and 55), and compares it to the 2014 Ferguson's riot map produced by CARTO and shared on Twitter. Both maps aim to represent the expansion of human

activity on a flat surface by stacking different slices of space and time to create the illusion of continuity.

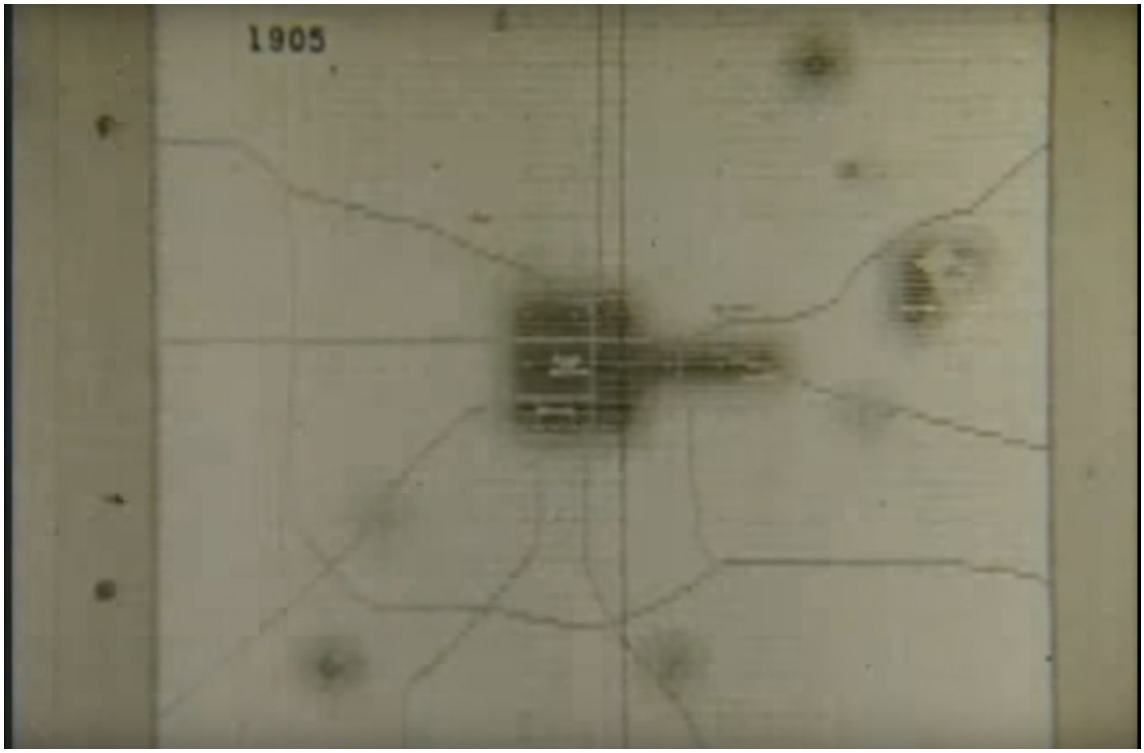


Figure 54 First screenshot taken from the YouTube video containing the recording of the original SYMAP animation of Lansing. It's interesting how the darkened area, which stand for the urbanized part of the town, slowly enlarging, look like mold eating progressively eating out of the pages of a old manuscript. The whole video is available at: https://www.youtube.com/watch?v=CGmVZfynTcI. Last accessed 27/09/2023.

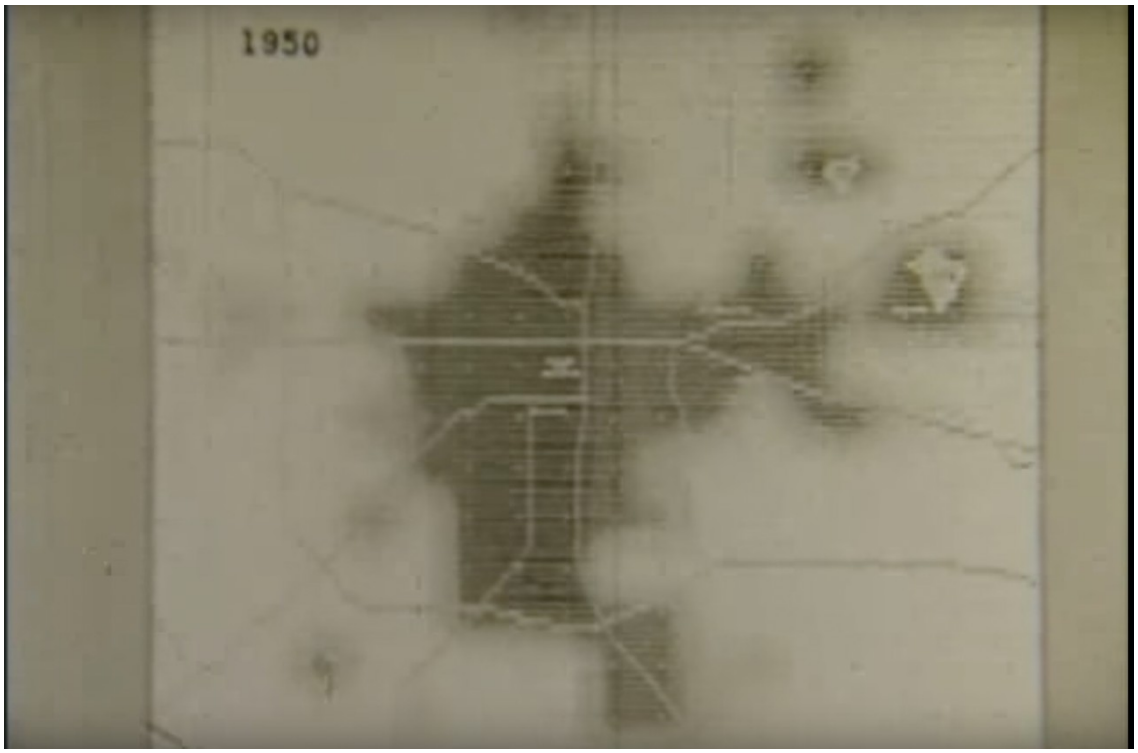


Figure 55 Second shot from the same video, to illustrate the progressive expansion in time of the urbanization process. Last accessed the same day Figure 53.

Wilson's critique of focusing on the lines of fracture within the moving map, following Haraway's suggestion (1996), centers on shifts in mapmaking norms within academia after World War II. The work of Arthur Robinson elevated "functional design" as a central concern in the relationship between mapmaking, map readers, and the mapped area. It was argued that innovations in mapmaking should align more with the objectivity of science than the artistry of representation. Ornamentation should not interfere with the representation of data. This desire to render mapmaking scientific was rooted in the advertising tradition, where studies on visual perception were gaining prominence.

While Robinson initially expressed skepticism about computational interventions in mapmaking, the convergence of his conceptualization with the historical trajectory of geography eventually established a Robinsonian tradition as a new norm. Wilson contends that this Robinsonian tradition forms the core of the advertised "location-aware future" (p. 76) promoted by contemporary digital location-aware platforms.

Despite the establishment of Neo-Robinsonianism in mapmaking, Wilson observes that this contemporary approach doesn't perfectly align with the nuanced perspective of Robinson himself. Robinson acknowledged the presence of certain subjective qualities in map-making that defy quantification, such as "harmony, beauty, balance, and proportion" (1952:73). These qualities, he recognized, were inherently subjective because they resided in the percipient—the one who perceives the image.

Efforts to "objectify" such subjective qualities have indeed been undertaken. For instance, Jaques Bertin (1967/1983), in his attempt to catalog all the variables that

cartographic design could encompass, ventured into the realm of quantifying the property of movement. However, he ultimately had to concede his inability to achieve this objective fully. Nevertheless, the field of behavioral cartography sought to advance the agenda of quantifying the perceptual qualities associated with moving images. Pioneered by authors like MacEachren (2004) and David DiBiase et al. (2006), these studies aimed to identify specific variants of the moving image that could yield predictable effects on the viewer's attention span.

It becomes evident that these later endeavors to control the ineffable aspects of the moving image were driven by the Neo-Robinsonian goal of efficient communication, particularly in the context of advertising. In this context, the moving map is perceived as a tool to assist consumers in their decision-making processes. However, critics like Danny Dorling and Stan Openshaw have argued for the profound generative quality of the moving image within geography. This generativity arises from the additional spatial dimension, building upon the work of Massey (2005), that is made possible by the gap between reality and its representation, facilitated by movement.

The moving image transcends mere efficiency and utility, which is the established trajectory embodied by the application of movement to GIS. The moving image could foster a space where the imaginative and the perceptual converge, offering a perspective that extends beyond quantifiable parameters. This perspective, as advocated by Dorling and others, embraces the richness of spatiality and the potential for new insights and understanding that arise from the dynamic interaction between reality and its visual representation through movement[19].

[19] This is not an exhaustive literature around animated cartography. Other text to consider are: Peterson (1995) *Interactive and animated cartography*: a technical text about map-making after the diffusion of digital tools, complete with examples and conceptualizations. Campbell and Egber (1990) essay "Animated Cartography/Thirty years of scratching the surface" provides a brief history of the development of animation, of new available techniques through

6.4 Before GIS

This historical framework provides valuable insights into characterizing the visual features of Lidar imaging, a pivotal visual technology in the realm of remote sensing for GIS. However, Wilson's selected genealogy of the history of animation in cartography doesn't encompass the very origins of this narrative. Experiments involving movement and maps can be traced as far back as the 1930s (Harrower, 2004). The first instance of a moving map can be found in a black and white newsreel produced by the Walt Disney Company in 1940 (Peterson, 1995). Interestingly, this moving map was not intended to depict reality but rather to convey the concept of invasion, illustrating the encirclement of Warsaw by the Nazi army during World War II. Even the map of Warsaw itself did not correspond to reality. The creation of this movie was an extremely labor-intensive and costly process, with every one of the hundreds of drawings required to create the illusion of continuity for the thirty-second duration of the reel meticulously hand-drawn, using the cartoon technique of "cels."

It was cartographer Thrower who, in 1959, advocated for the development of animation within the field of geography. It's important to keep in mind the post-World War II shift that influenced the field of map-making, steering it towards a more scientific approach, as we delve into this historical context. Thrower's piece on animated cartography begins by emphasizing how the need for "audio-visual aids" was officially recognized as a central tool in both education and economic production through the 1958 National Defense Education Act. The article goes on to explain that a significant allocation of economic

computer graphics to provide scientific visualizations, especially in the field of thematic cartography. Harrower's 2004 paper, "A look at the history and future of animated maps", provides a history of sixty years of development of animation in map-making, proposing a periodization centered around production techniques and diffusion.

resources was mandated by law for research, experimentation, and the development of new media. The subsequent section is noteworthy and deserves to be quoted in full:

> Live-action motion pictures have been used with great success for a variety of instructional purposes in the armed services, as well as in schools and in industry. To illustrate processes which cannot otherwise be seen o r which require simplification, animated drawings have been effectively utilized. Great liberties can be taken with timing in such movies; processes occurring over a long period can be speeded up while rapid motion may be slowed down permitting observation and comprehension of complex phenomena. The sound track, of course, is essential for maximum effectiveness in this method of mass communication. Although in the past the animated drawing has been associated particularly with entertainment and advertising, it is being used increasingly for scientific illustration. Maps lend themselves particularly well to animation; by the use of this technique we can add another dimension to cartography --time. In an effort to combine the historical with the geographical approach cartographers have used what Andrew Clark has called, "instantaneous cross sections of area". (1959:10).

In just a few lines, the cartographer underscores the strategic importance of animation in a broad sense, as well as the significant temporal dimensions that can be captured and crafted through this medium. The subsequent section of the article provides a highly detailed set of instructions on the technical aspects of producing the drawings required for creating an animated map. It also emphasizes the importance of a script to narrate the events portrayed in the video.

Thrower's explanation of how "area, point, and line symbols used on a map are relatively easy to animate" brings to mind Sean Cubitt's exploration of animation through the act of drawing lines within the realm of visual technologies at large (2015). In his second chapter, the media theorist traces a line from Dürer to Disney, passing through Descartes and Hogarth. This line follows the dialectic between control and freedom, where a gesture can be constrained at times and then liberated again within the fractures of visualization, for art and science. Cubitt reports how the lineage of cartoons from the 1920s still retains the freedom evoked by nightmarish and medieval depictions of monsters that persisted beyond the Enlightenment. These monsters found expression in pre-filmic media, ranging

from shadows cast in firelight to optical toys that emerged in seventeenth-century Europe, such as camera obscuras, magic lanterns, shadow puppets, trompe l'oeil paintings, and optical toys (Cubitt, 2015:66).

The advent of Disney pictures, marked by the emergence of Mickey Mouse, introduced what Cubitt describes as the "innocent line" (2015:67). This particular approach to drawing and character narrative, while depicting animals, constructed the trope of the innocent leader. Stories featuring Mickey Mouse and his companions managed to eliminate themes of sex and death. Cel animation, a technique developed over two decades by Disney animators and protected by a series of patents, was a costly and labor-intensive innovation. Its purpose was to streamline the animation process. Graphite markings were traced onto transparent sheets made from various materials and placed on a backlit surface to aid in drawing subsequent frames while maintaining continuity. Additionally, inking the pencil drawings was a meticulous process that required strict adherence to the line to ensure continuity, with no variations in width. Metronomes were employed to synchronize the moving image with the soundtrack. This technical history, focusing on materials and human processes towards abstraction (of the drawing) and standardization (of technique), forms the essence of the history of animation. It's a narrative marked by a dialectic of life and death, where animation breathes life into drawings and constructs a symbolic boundary against death, as explored also by Bazin (1967). However, what is repressed tends to resurface and haunt.

In his exploration of animated cartography in the context of GIS and computer graphics, Wilson highlighted a comment made by Field, an employee of Esri, a multinational GIS software company, in response to the proliferation of animated maps on social media.

Field's tweet pondered when people would realize that the animated maps shared on platforms like Twitter don't convey meaningful information (Wilson, 2017:79).

This skepticism towards moving/animated images in conveying meaningful content is an aspect of contemporary image culture to further explore. While we could delve into the intricate narrative of life and death, abstraction and representation within the history of animating static images, which brings us to the realm of vector graphics, an alternative perspective emerges.

Farocki, in "Phantom Images" (2004), introduces the concept of "phantom shots" in the USA film industry. These are shots captured from perspectives impossible for the human body to occupy. Furthermore, he introduces the term "phantom-subjective images" to describe images captured from the perspective of unmanned military devices, like what were termed "intelligent bombs" in the 1990s. Reflecting on the dialectic of animated images, Farocki explains how they create a world where everything is indefinite, processes can be reversed, and they symbolically guard against death while challenging the indexicality of photography. They also exist in the middle ground between creative expression and industrial or scientific applications.

When analyzing emerging images from the battlefield, Farocki observes that the targets of projectiles are never humans but rather objects like barracks, buildings, and bridges. Even cars, which would imply the presence of a human driver, are somewhat removed from these targets. Farocki refers to these machine-captured, phantomatic subjective shots as "operative" images, drawing on Roland Barthes' analysis of current social mythologies (1957). Operative images depict processes that no human could witness, challenging the

notion of the artist as an intentional author. They possess an uncanny formalism that allows for the emergence of an "unconscious visible" (p. 18).

As we delve into the realm of Lidar videos, it becomes imperative to grasp the profound relevance of the history of how animation and cartography became intertwined. This historical exploration sheds light on the intricate relationship between space, time, and representation in Lidar videos, unraveling their conceptualization.

Animation and cartography have shared a long history of mingling and evolving, and understanding their convergence provides valuable insights into the nature of Lidar videos. Lidar technology captures the world in fine-grained detail, translating it into digital representations that, in many ways, resemble animated cartography. It's in this convergence that we encounter a complex interplay of elements: animation techniques, cartographic conventions, temporal considerations, and spatial interpretations.

The notion of "operative" intentionality that blurs the lines between art and science, information and persuasion, is particularly relevant here. Lidar videos are not merely static representations, but dynamic and purposeful creations, as evidenced by their aesthetic repurposing for distribution on social media and proprietary sites. We have seen, in previous sections, how moving maps have been used on social media to “move” an audience, as the latest incarnation of a cartographic tradition that has turned towards the means of film and animation to convey information in a captivating manner, for a series of very different reasons – from pedagogy, socio-economics, through the experimentation of cognitive effects, to straight-up propaganda. Lidar videos too, carry a form of "operative" intentionality — they aim to convey specific information, influence perceptions, and enable various forms of analysis, as the visual output of an epistemic tool. Therefore, understanding how animation and cartography have been historically tied together helps

appreciating the multistable intentions inscribed in Lidar sensors and the cognitive effects of the Lidar videos they produce. While Lidar remote sensing is primarily designed to capture data from the environment for modeling purposes, it can also be deployed for various other objectives. For instance, to exactly track the trajectory of a bullet (see Figure 56) -- a dramatically different purpose compared to recognizing pedestrians to avoid casualty in automated urban sites.



Figure 56 Screenshot taken from a video titled AEye's LiDAR Tracks a Speeding Bullet. Available at https://www.youtube.com/watch?v=TyIf6kEyERg. Last accessed 14/03/2024.

In considering the role of the researcher as spectator, I draw parallels with Laura Mulvey's concept of the DVD movie spectator (Mulvey, 2006). Lidar video viewers are not passive observers but active participants who can manipulate the temporal dimension of the video, pressing just a button. They have the power to fast-forward, pause, or skip segments, disrupting the traditional sense of continuity. This mirrors the way Lidar technology itself disrupts our conventional understanding of space and time by capturing and representing them in novel ways.

In the context of Lidar videos, as a researcher, I'm dissecting not a physical entity, but a digital representation of space and time, to scrutinize its layers and implications.

The historical entanglement of animation and cartography equips us with the critical tools to comprehend the relationship between space and time in Lidar videos, as they are manipulated through perspective. It enables us to navigate the complexities of representation within this contemporary visual medium, offering a deeper understanding of how Lidar videos shape perceptions of the world.

6.5 Lidar videos

Before closing the chapter on animated cartography with a call for interdisciplinary studies and inquiries, Wilson puts together in their reflection upon the meaning of movement in the visual image one of the authors of the algorithmic turn in GIS with the work of a cinema theorist. In his words, just after having presented and commented Dutton's work (*Hexagonia*, 2015), an example of moving holographic mapping:

> More than an artifact for precisely measuring the effective- ness of cartographic design, these animations illustrate what Rancière identifies in the troublemaking of cinema: "The art of cinema cannot only be the deployment of the specific powers of its machine. It exists through the play of gaps and improprieties."[63] Danny Dorling puts this differently, although just as aptly. "Cartographic animation is a strange concept. To animate means to create the illusion of movement."(Dorling, 1992:215 in Wilson 2017:91).

This coupling of cinematic thought with problems connected with understanding and representing space is also specifically developed by Dickeç (2015), in an engagement with Rancière's thought, among others, that is more focused on political aspects rather than aesthetics. But in this narration of fractured developments, exchanges,

metamorphoses and ambiguities, it might be worth considering how, for Rancière, the moment of the political and the moment of the aesthetical are interconnected in creating a stage that allows for certain actions to be taken or not. When it comes to the aesthetic side of this creation of an organization of materialities (my own translation, in this site, for "partage du sensible"), movies offer a fable, a fiction, that can help open up horizons of possibilities for action (Rancière, 2000; 2001; 2008).

As we have seen, animated cartography should be organized around a script, but, obviously, this script can offer a narrative, or not. Lidar imaging, as we have seen, is often inscribed within a thick framework of rhetorical discourse, but what kind of non-narrative script does it offer? What kind of fiction, in the wider sense of the organization of materialities, it inaugurates? In the task of taking seriously Lidar imaging, like Beer, going beyond the mere *surface* of the discourse that wants to sell a logic, how does the logic operate? To investigate this formal side of Lidar imaging, I turn to Bertetto's methodology (2006), who, among other approaches, suggests the possibilities of interrogating a movie, taking seriously the visual organization of the filmic scene, and investigating sense-making through recognizing the importance of the grammar of cinema, which is materially and cognitively inscribed in filmic techniques. Part of this use is determined by how geographers themselves have conceptualized the utilization of movement, in conveying geospatial information. However, it should be noted how the medium of animation is phenomenologically different from a real-action movie, the same way Lidar imaging is different from photogrammetry, paying attention to the graphical aspects of the presentation, as noted before in this chapter.

In this analysis, I have specifically focused on videos sourced from the YouTube channels of the companies previously scrutinized in the website analysis conducted in the

previous chapter. The selection of YouTube channels as source material offers a comprehensive view of these companies' evolving marketing strategies and provides insight into the types of geo-visual content they use to support their progress. Additionally, YouTube channels often undergo content changes less frequently than company websites, making them a valuable resource for longitudinal analysis.

It's important to note that I have chosen to concentrate solely on videos that prominently feature proprietary point clouds. However, it's crucial to reiterate that, similar to my previous analyses, the issue of reliability remains. Many of these point clouds may lack adequate geo-temporal references, making them difficult to verify for accuracy.

Approaching the analysis of these videos involves viewing them as a unique form of animated movie. This perspective allows us to explore the visual narratives and storytelling techniques employed in these videos, enabling a deeper understanding of how companies utilize proprietary point clouds in their communication strategies.

In continuation of the previous chapter, I explored videos created by the same sample of companies, accessible on their respective YouTube channels. In conducting my visual analysis, as specified before, I accorded priority to the formal qualities that define the presentation of Lidar imaging. This involved an emphasis on elements such as framing, montage, color choices, and prevalent shapes (Bertetto, 2010; Rose, 2022). While my intention was to primarily focus on aesthetic elements, it became inevitable that discursive elements played a significant role in imbuing meaning into the images in certain instances. Notably, elements such as humor and the use of metaphors emerged as pertinent aspects within the analytical framework.

6.6 Framing

In the presentation of AEye's proprietary ecosystem for data collection and planning, the initial frame of the video resembles a photograph of a cinema entrance. The point of view is slightly tilted, focusing on the red lights atop the entrance gates and the plaza leading to the complex, which is reserved for pedestrians. The scene features distinctive eye-shaped planters arranged in two rows along the square. The geometric shapes and planes, with their beige and red color palette, contrast against the modern building and the blue sky with white, sunlit clouds. A black wrought-iron streetlamp frames the picture on the left, while cars are parked along the outer edge of the cinema. On the right, movie posters complete the scene (see Figure 57).

Subtitles in the video indicate that this scene was "filmed" at the Regal Hacienda Crossings Stadium in Dublin, California. Given this context, it is reasonable to assume that the video demonstrates data collection and visualization for future applications in smart transportation rather than a software training simulation. This aligns with the company's marketing objective of showcasing the capabilities of their integrated system, which combines data from cameras and Lidar into a coherent whole, processed by computer vision algorithms for meaningful insights.

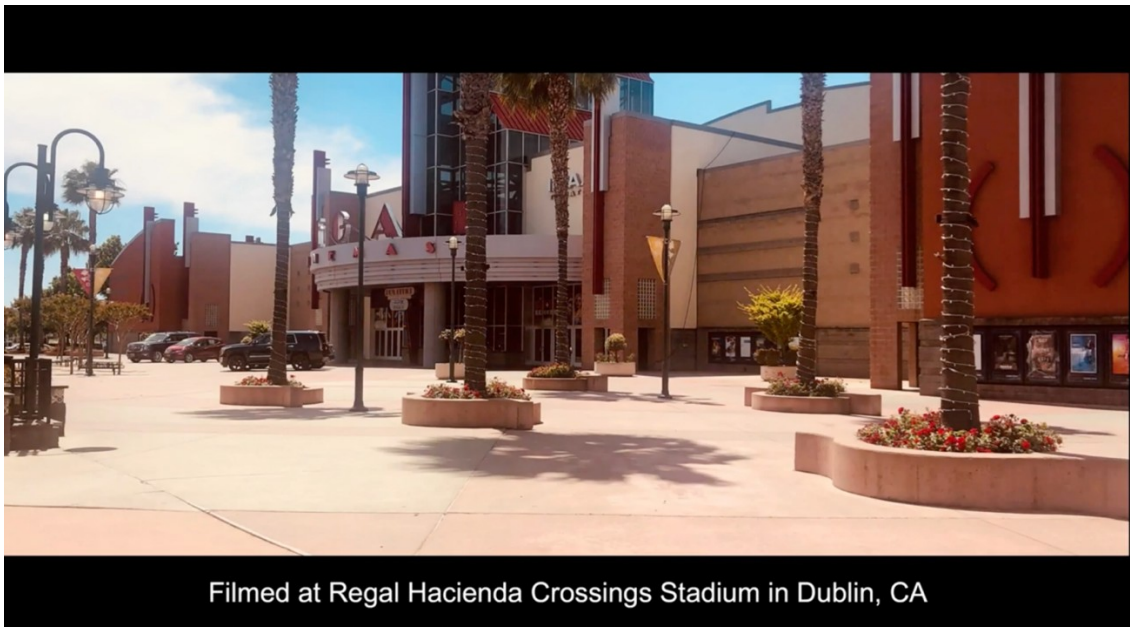


Figure 57 Screenshot taken from the video available on AEye YouTube channel at: https://www.youtube.com/watch?v=U-s4e2MIjo4. Last accessed 14/03/2024.

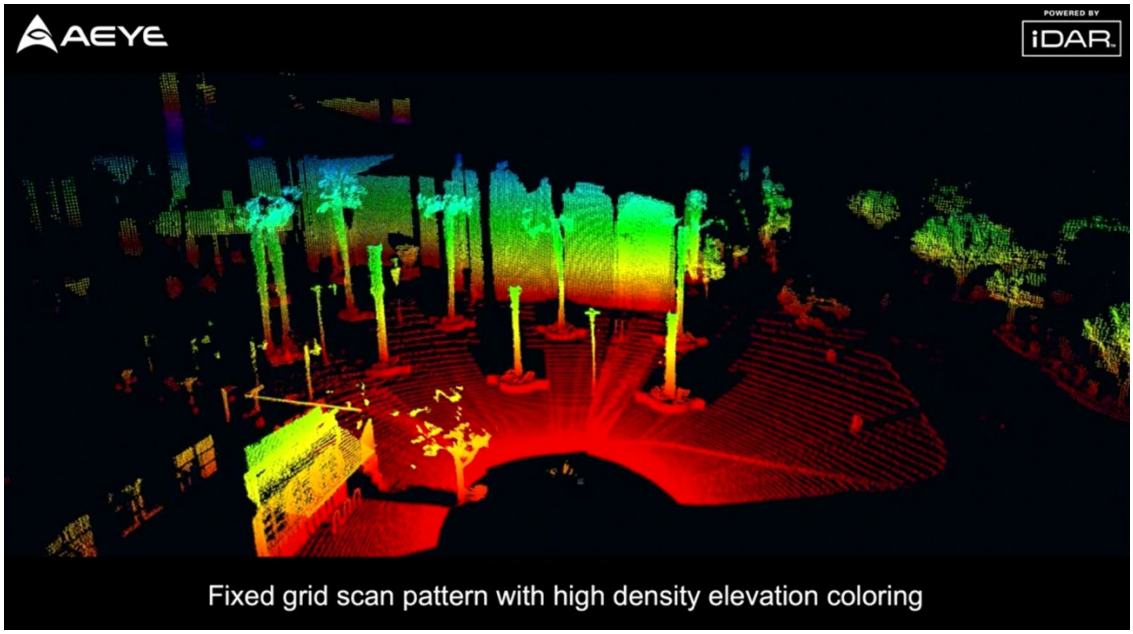


Figure 58 Screenshot taken from the video available on AEye YouTube channel at: https://www.youtube.com/watch?v=U-s4e2MIjo4. Last accessed 14/03/2024.

AEye's press release from 2017 likens their ecosystem to the mechanics of the human visual cortex, a metaphor that has been the subject of ongoing debate among scholars regarding the comparison between software and the brain/mind. The presentation goes on to explain how their algorithms are designed to infer the colors of a scene that has been data-mined. However, this description raises doesn't provide details about the precise role

of the algorithm in combining distance information and pixels color information. This ambiguity adds an eerie quality to the initial image in the video.

The doubt is further enhanced by the surreal quality of the sunny image, which depicts a Californian city devoid of people. The movie posters in front of the cinema, known for its IMAX projections, contribute to a sense of unease. It prompts one to wonder whether the external scene is a "filmed" image, as the subtitles suggest, captured by a camera or if it is a digitized reconstruction. This uncertainty is intensified by the absence of human presence in a city square on a sunny day. The only signs of humanity are a few parked cars just outside the plaza, implying the presence of anonymous individuals who remain unseen, adding to the haunting atmosphere.

Subsequent images in the video are renderings of the same building and plaza, but the perspective shifts to an aerial view, as if the data were collected by a drone hovering above the city. AEye demonstrates different Lidar scanning patterns within their ecosystem, with one pattern using rainbow coloring to differentiate object distances (see Figure 58). Another pattern retains the same coloring but introduces moving lines and dots, likely a consequence of the sensor's architecture.

The subsequent scenes aim to highlight the ecosystem's strengths, with algorithms assigning different colors based on point type. For example, passive objects are assigned orange, while moving objects are designated as green. This approach enables the detection system to allocate Lidar resources selectively to objects that require tracking due to their movement. AEye claims that this process allows their system to "see only what matters." Beyond the marketing rhetoric, the images reveal complex geometries that are central to their technology.

The visual representation of extracted data is displayed from an overhead perspective, with edge recognition being a primary task of the algorithm. The identified elements within the scene are outlined with a neon green border against a black background. The scanning pattern is especially visible on the ground and, with varying intensity and colors, above the surfaces of buildings and the organic structures of tree canopies. This scan pattern reveals the position of the sensor, which is located at the center of the crossing. The choice of this specific viewpoint for the presentation appears to be driven by aesthetic considerations, as it creates a striking contrast between the initial view of the plaza and the subsequent perspective composed of moving lines and dots. The visual cues that establish continuity between the initial scene and the data rendering are the eye-shaped planters and tall palm trees. Some of these trees appear to be missing their lush crowns, which could be attributed to either the natural loss of leaves or limitations in the sensor's scanning capabilities.

The complexities of data mining and visual rendering are further highlighted in another video by the company titled "Virtual Driving Demo for Automotive Applications," which was presented at CES 2022 and is available on the company's YouTube channel. In this ten-minute demonstration, guided by a soothing voiceover, viewers are taken on a "three-dimensional journey" through Las Vegas[20].

[20] This can be seen as a declension of the use of specific places in tourism advertising to capitalize on the iconic value of certain geographical locations. See: Fleming and Roth (1991) Place in Advertising; Pike (2009) Geographies of brand and branding.

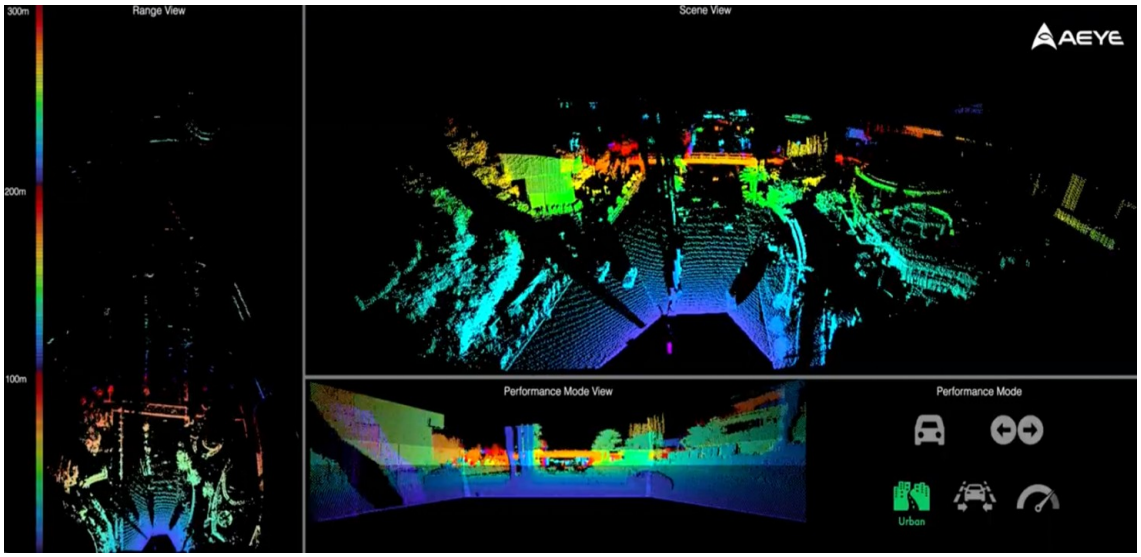


Figure 59 Screenshot taken from the video available on AEye YouTube channel at: https://www.youtube.com/watch?v=l2whrGnxJ4s. Last accessed 14/03/2024.

The presentation employs a tripartite split screen format (see Figure 59):

1. On the left portion of the screen, viewers can observe the sensor's range, which is displayed from an almost perpendicular viewpoint to the ground, resembling a satellite view. The rainbow coloring, favored by the company, is used here in a repeating cycle every 100 meters, creating a spatial rhythm akin to a colorful symphony of distances.

2. The upper part of the right screen offers a bird's-eye view of the road ahead of the vehicle, providing an "overview of the entire scene," as explained by the presenter's voice.

3. The lower part of the right screen is referred to as the "performance mode view," resembling a "subjective point of view" in terms of traditional cinematic analysis. It immerses the viewer in the middle of the street, allowing them to experience the road as if their human eyes were merged with machine vision.

The framing and presentation choices in this video underscore the idea of merging human and machine point of view, blurring the boundary between human perception and machine vision[2122].

In the video presentations, the system showcases its ability to adapt to different urban environments and scenarios, such as highways, city streets, parking lots, and intersections. However, a recurring theme throughout these demonstrations is the absence of human presence in the perceived environment. The sensor system can detect and reproduce various distinctive features of urban settings, but these landscapes appear unfamiliar and uninhabited. Human figures, when introduced into the scenes, are often indistinguishable from other objects, raising questions about the system's capacity for recognizing and identifying human features.

In the "Virtual Intersection Demo for ITS Application", the system is tested in various junctions, including those with pedestrians crossing (see Figure 60). While the system can perform correctly, the impression of an uninhabited city persists, echoing the initial virtual trip outside the cinema in Dublin, California.

[21] Here I'm following an important point made by Bissel and Fuller (2017). In spite of how the technoscientific culture might appear devoted to science and completely hollowed out of values connected to theology, a point sustained with insistence by Stiegler (2002), it appears that themes connected to the sacred are still very much alive in the relationship between images and their producers and consumers. Bissel and Fuller mention Mitchell's taxonomy of the survival of instances of magical thought in the agency of images (2005). They also refer to Didion's work (2005). These studies can be traced back to Durkheim analysis of how religious subtext forms the basis for group identity in society (1912/2016). The "theological", so to say, subtext in technoscience has also been picked up by critical data scholars like Chun (2011) and David Beer (2018).

[22] Phenomenon of identification and substitution in the art of navigation has always happened: an interesting historical example is represented by the evolution of the figureheads that adorned the bows of ships until XIX century. The tradition of figureheads is ancient, dates back to the Egyptians, and since the beginning, it represented the deployment of an apotropaic figure to bring luck to sailors. Literature recounts how this apotropaic gesture often brought about a sort of identification between the ship and the commander of the ship. In a sense, the eye of the wooden figure represented the eye of the commander, capable of looking where vision was prohibited to sailors (cfr. Magris, 2019). During the 1700's the idea was that the figurehead could command, because of its aesthetics, the mightiness of a nation. The Royal Navy then started regulating the making and deployment of figureheads, with the intention of eliminating them, an attempt that failed. The tradition of figureheads fell int0 disuse when marine and army ships started to be made in steel, and their design subsequently shifted (Pulvertaft, 2011).

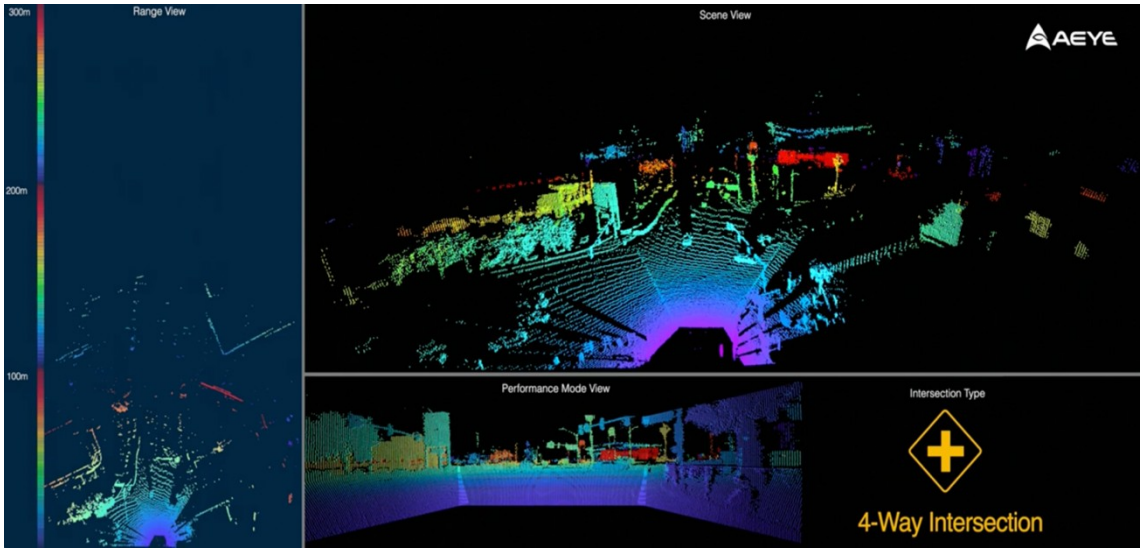


Figure 60 Screenshot taken from the video available on AEye YouTube channel at: https://www.youtube.com/watch?v=D5Ant8Ty0Pw. Last accessed 14/03/2024.

One key takeaway from these demonstrations is the representation of space, which lacks the presence of inhabitants or pedestrians. Additionally, the elision or blending of human features within the scenes challenges the viewer's ability to identify and distinguish human figures from other objects in the environment.

A different take on perspective is offered by Aeva's YouTube videos showcasing their Lidar technology offer insights into the capabilities and unique features of their system. These videos are short, typically lasting no longer than 30 seconds, and are presented without audio commentary. Instead, the titles of the videos provide clear descriptions of the content and objectives of each video, both as headers and within the video itself.

One of Aeva's key strengths highlighted in their videos is the exceptional range of their Lidar system. In the video titled "Aeva ultra long-range object detection and tracking," the point cloud visualization captures a road scene with rows of trees along the sides and sporadic oncoming cars. Initially, the viewer is placed in the subjective point of view of

the car, but the perspective then rises smoothly to provide a high bird's-eye view. This visual demonstration effectively showcases the sensor's impressive range, capable of capturing and "seeing" objects and landscapes at distances of up to 500 meters (see Figure 61, 62, 63 and 64).

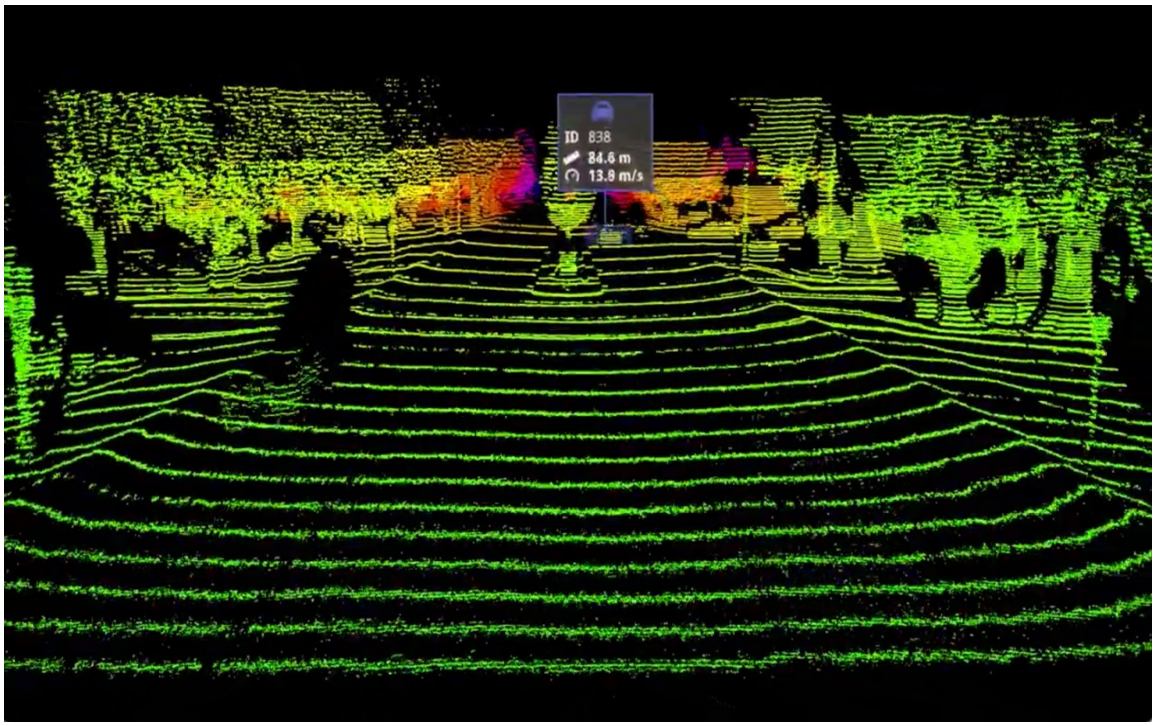


Figure 61 First of a series of screenshot taken to show the changing in point of view. Full video available at: https://www.youtube.com/watch?v=8n65IypJJ50. Last accessed 14/03/2024.

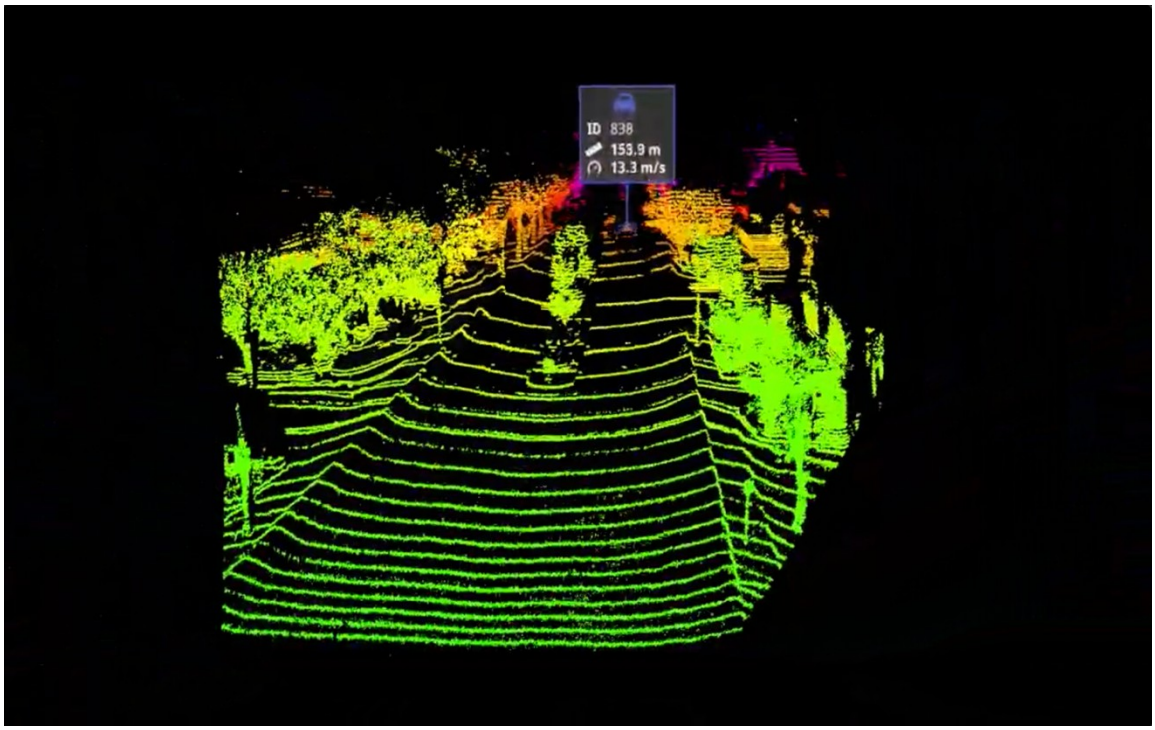


Figure 62 Second of a series of screenshot taken to show the changing in point of view. Full video available at: https://www.youtube.com/watch?v=8n65IypJJ50. Last accessed 14/03/2024.

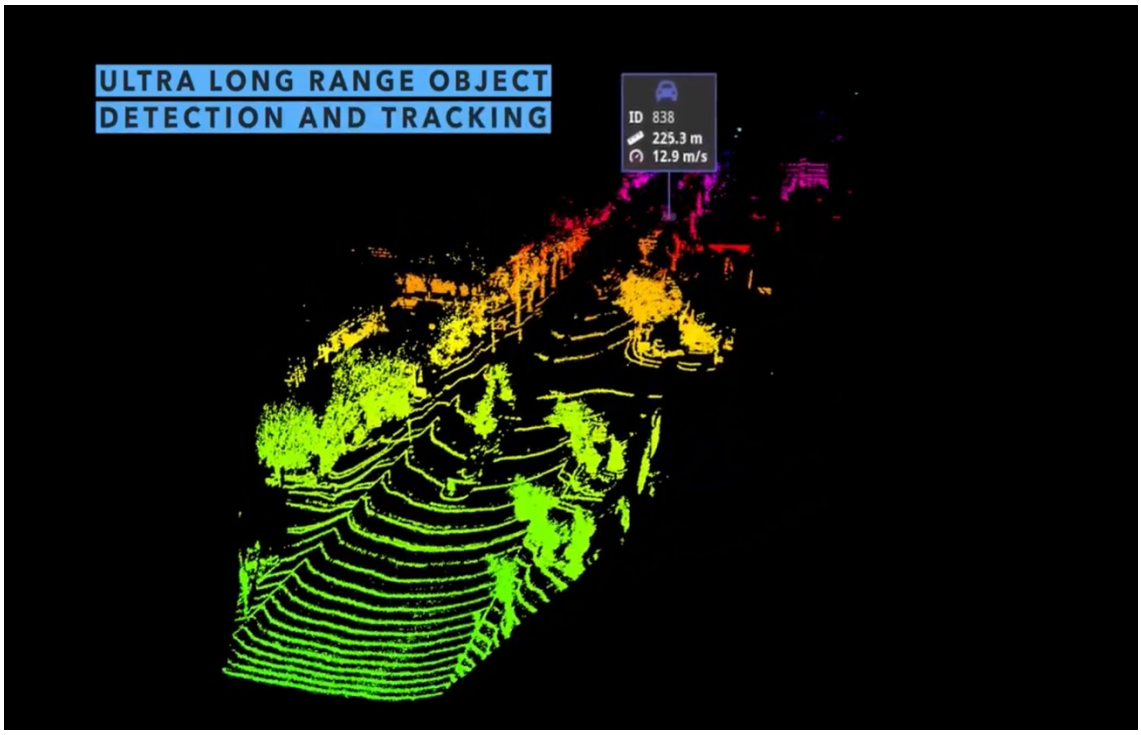


Figure 63 Third of a series of screenshot taken to show the changing in point of view. Full video available at: https://www.youtube.com/watch?v=8n65IypJJ50. Last accessed 14/03/2024.

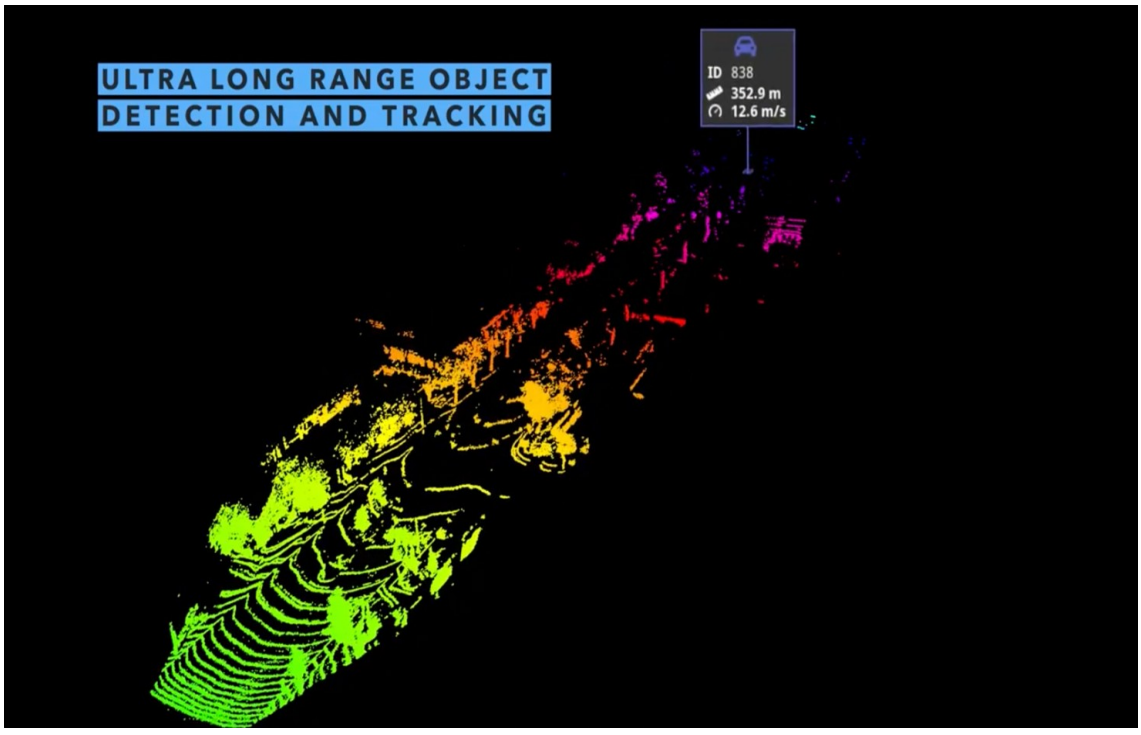


Figure 64 Fourth of a series of screenshot taken to show the changing in point of view. Full video available at: https://www.youtube.com/watch?v=8n65IypJJ50. Last accessed 14/03/2024.

Aeva also showcases the subjective perspective of the car, with a video that puts the viewer at the same height as the sensor, while proceeding on the road. The video suddenly

stops, freezing the travel in time. Then, a fast zoom brings the focus to a distant object, that is rapidly enlarged, appearing composed of dots bounded by a semantic box, signaling how the software has quickly recognized an object on the road that might reveal itself to be a source of danger for the cruising of the vehicle (see Figure, 66 and 67).

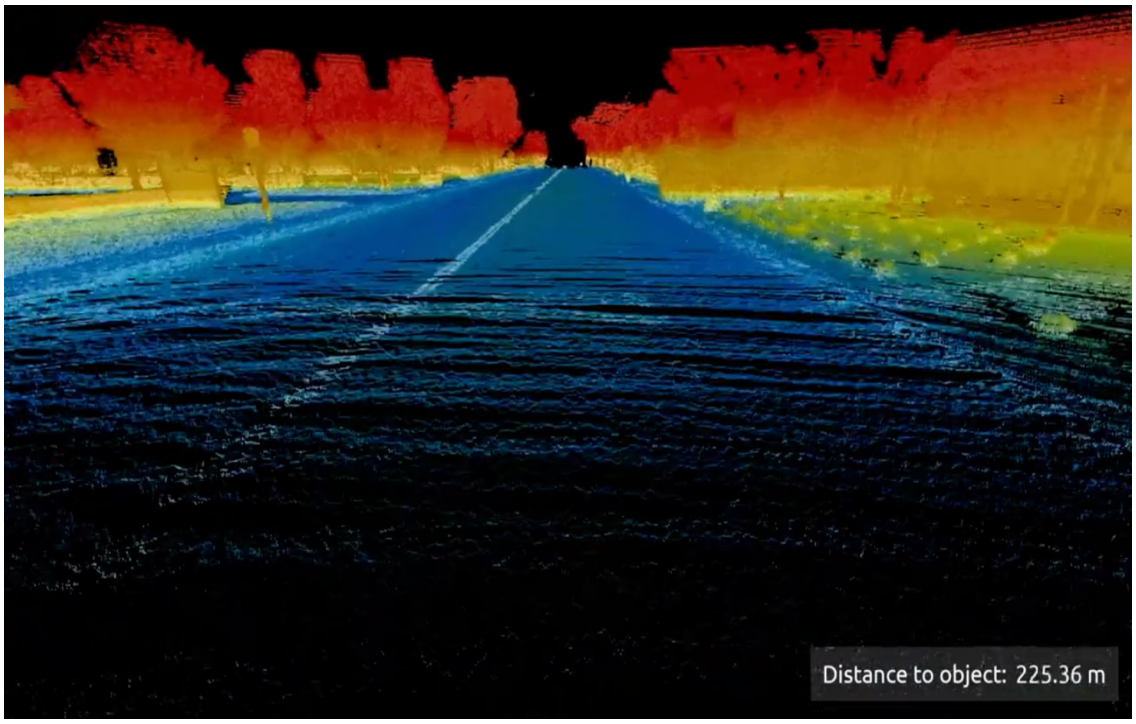


Figure 65 First of a series of screenshot to show how the brand visualizes the detection of velocity. Full video available at: https://www.youtube.com/watch?v=R2PZj7hFRXQ. Last accessed 14/03/2024.

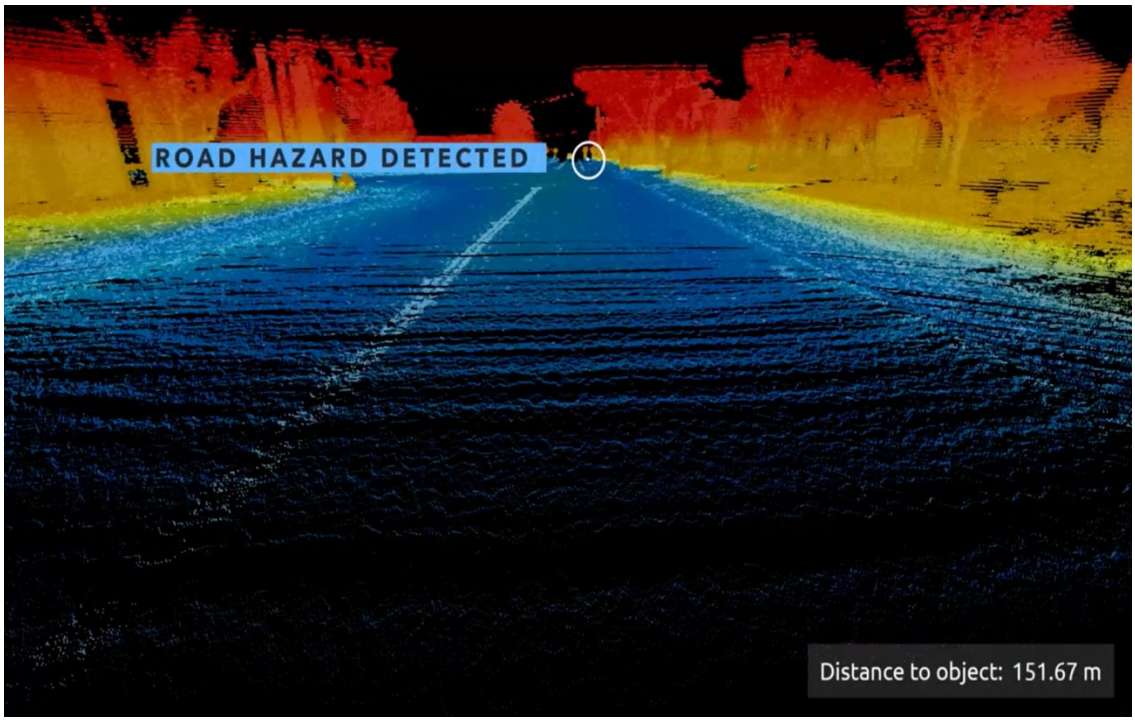


Figure 66 Second of a series of screenshot to show how the brand visualizes the detection of velocity. Full video available at: https://www.youtube.com/watch?v=R2PZj7hFRXQ. Last accessed 14/03/2024.

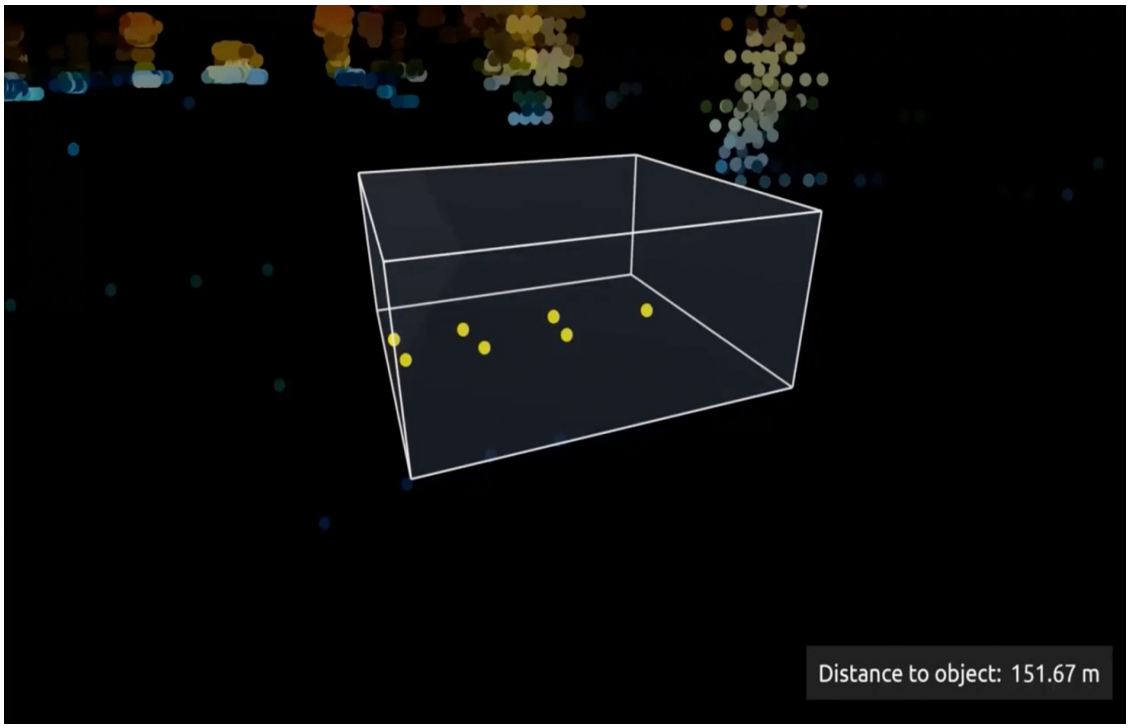


Figure 67 Third of a series of screenshot to show how the brand visualizes the detection of velocity. Full video available at: https://www.youtube.com/watch?v=R2PZj7hFRXQ. Last accessed 14/03/2024.

Innoviz's videos also offer a glimpse into the challenges of perceiving the world through the eyes of a car equipped with Lidar technology. As the perspective shifts, zooms in and

out, and pans across the scenes, the points that compose objects, people, and the ground become scattered and fragmented. These points take on different shades of brown, resembling scattered stars in the night sky. The abundance of points, each representing a distance measurement, can be challenging to organize, for the human viewer, when the shapes no longer resemble coherent surfaces (see Figure 68 69, 70 and 71).



Figure 68 First of a series of screenshot taken from https://www.youtube.com/watch?v=wmcaf_VpsQI last accessed 14/03/2024.



Figure 69 Second of a series of screenshot taken from https://www.youtube.com/watch?v=wmcaf_VpsQI last accessed 14/03/2024.

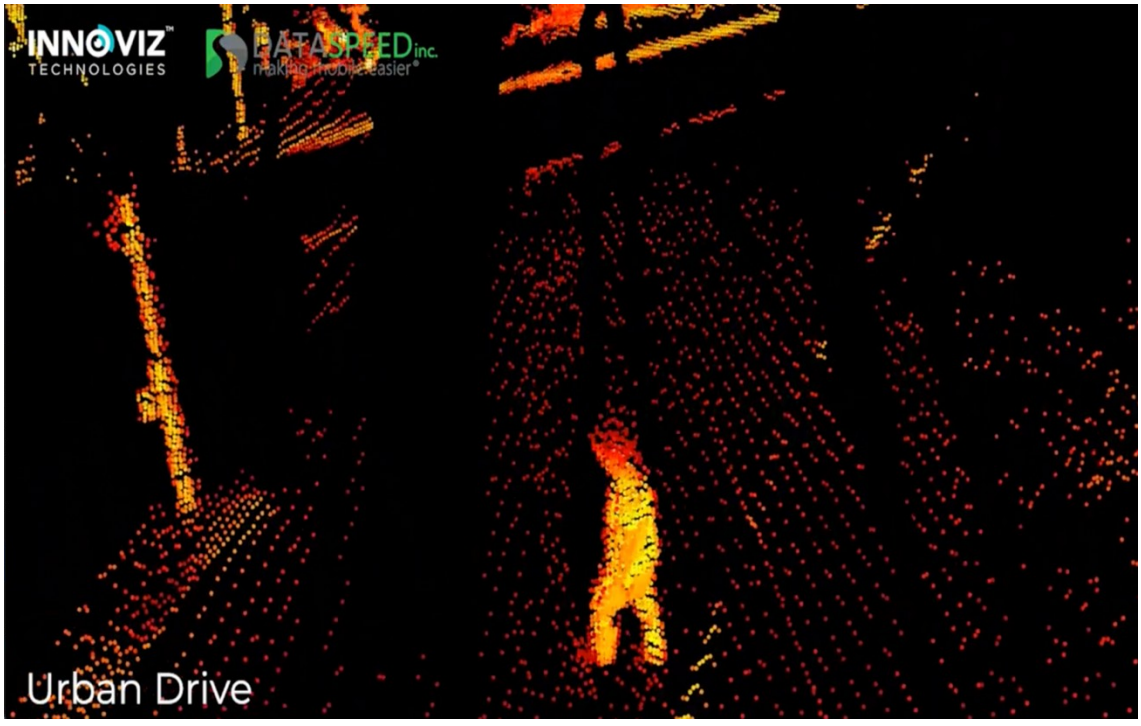


Figure 70 Third of a series of screenshot taken from https://www.youtube.com/watch?v=wmcaf_VpsQI last accessed 14/03/2024.

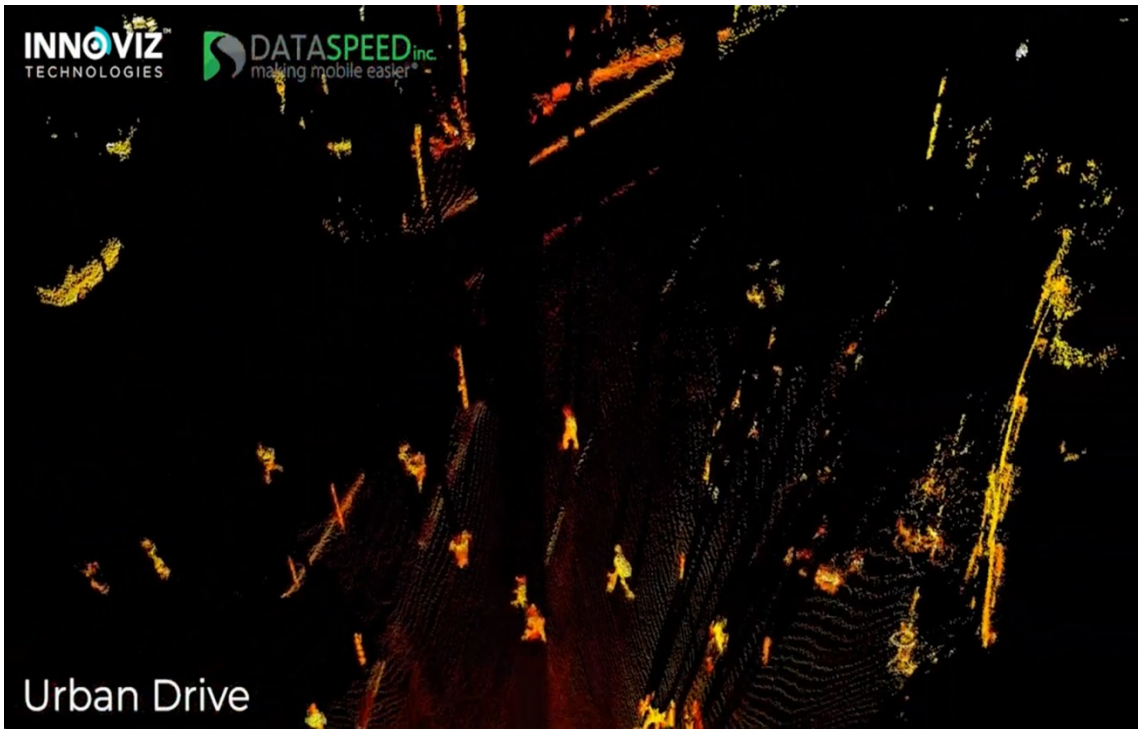


Figure 71 Fourth of a series of screenshot taken from https://www.youtube.com/watch?v=wmcaf_VpsQI last accessed 14/03/2024.

This observation raises an essential point about Lidar technology: while the data collected are inherently three-dimensional, they are projected onto a two-dimensional screen for human interpretation. The screen serves as the interface between the two-dimensional logic of maps and the three-dimensional logic of cyberspace (Farinelli, 2009:96). The mathematical properties and implications of these different geometries, especially in terms of how they relate to human perception and understanding, will be further explored in the next chapter.

A similar but different iteration of this constellation of data videos is offered by Luminar and their video demonstration from CES 2019. In this video, Luminar showcases Lidar point clouds in more extensive detail, particularly focusing on a point cloud of Venice Beach. The video employs a dynamic play between zooming-out movements and slanted angles, synchronized with a catchy musical beat. The point cloud reveals a vibrant and

bustling Venice Beach Square with arcades framing the road and festoons hanging overhead. This digital representation resembles an upbeat cyberpunk ideal city[23] (see Figure 72).

Importantly, the Venice Beach point cloud is not devoid of life. It captures various individuals in different activities, frozen in time. Pedestrians cross the road, tourists take pictures, and someone even prays at an altar—all suspended in their actions. Meanwhile, the machinic rendering moves through the points reconstructing surfaces, creating an ethereal and ghostly effect. It blurs the boundary between ground and sky, and its dynamic colors pulse like a digital rainbow (see Figure 73-82).



Figure 72 First of a series of screenshot taken from: https://www.youtube.com/watch?v=8uMPqp_Xz5g last accessed 14/03/2024.

[23] Vanolo (2014) provides a reading of the "good city" within the framework of renewing the city through smart technology.



Figure 73 Second of a series of screenshot taken from: https://www.youtube.com/watch?v=8uMPqp_Xz5g last accessed 14/03/2024.

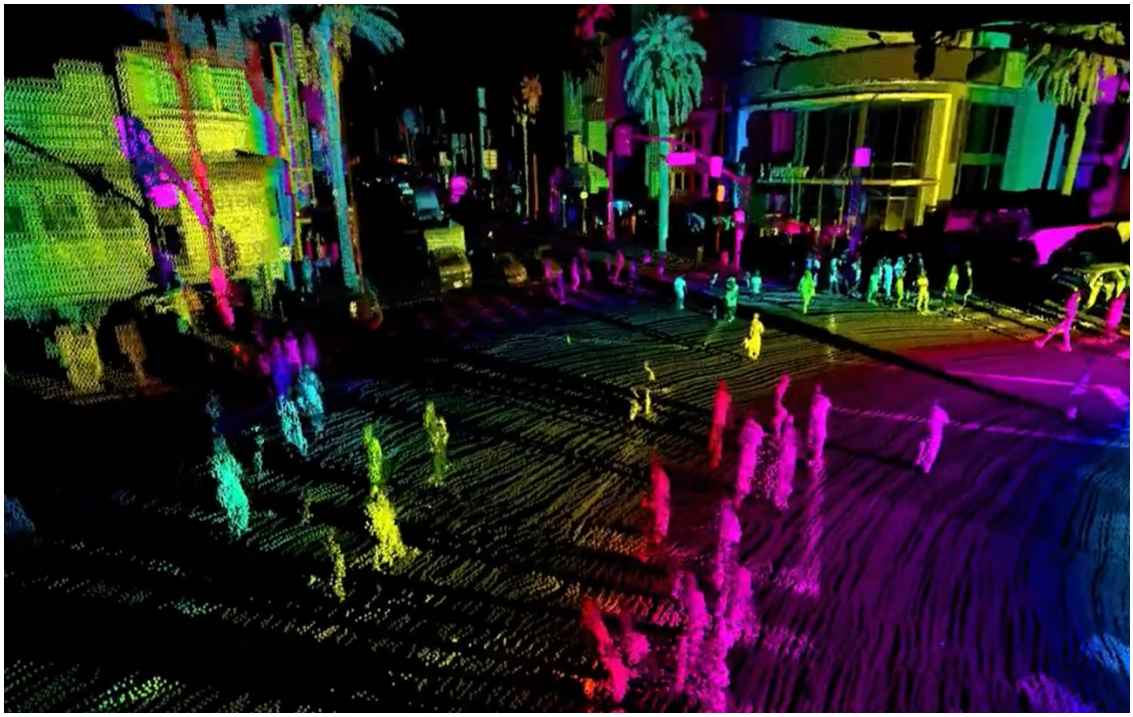


Figure 74 Third of a series of screenshot taken from: https://www.youtube.com/watch?v=8uMPqp_Xz5g last accessed 14/03/2024.

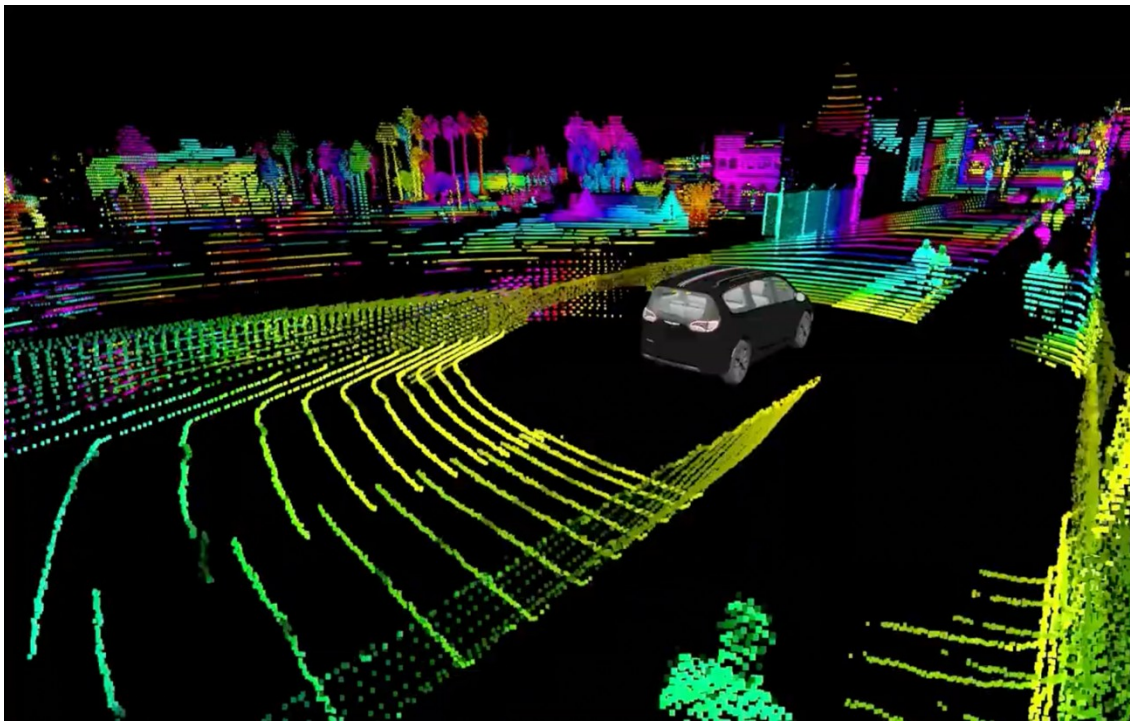


Figure 75 Fourth of a series of screenshot taken from: https://www.youtube.com/watch?v=8uMPqp_Xz5g last accessed 14/03/2024.

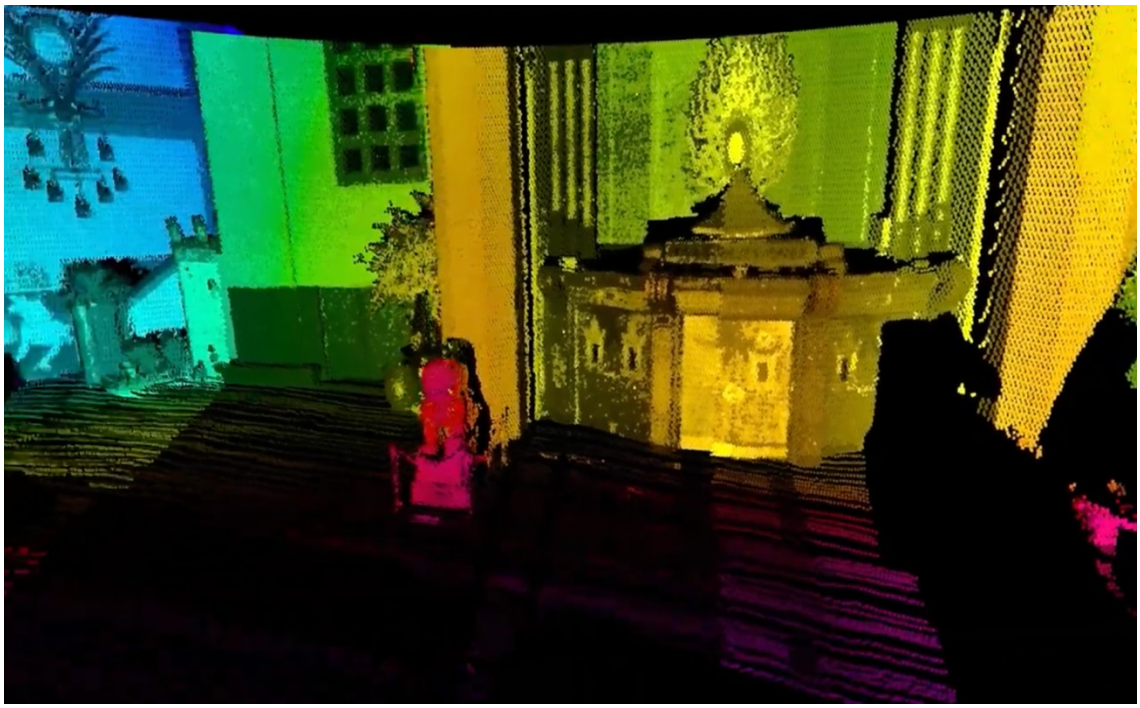


Figure 76 Fifth of a series of screenshot taken from: https://www.youtube.com/watch?v=8uMPqp_Xz5g last accessed 14/03/2024.

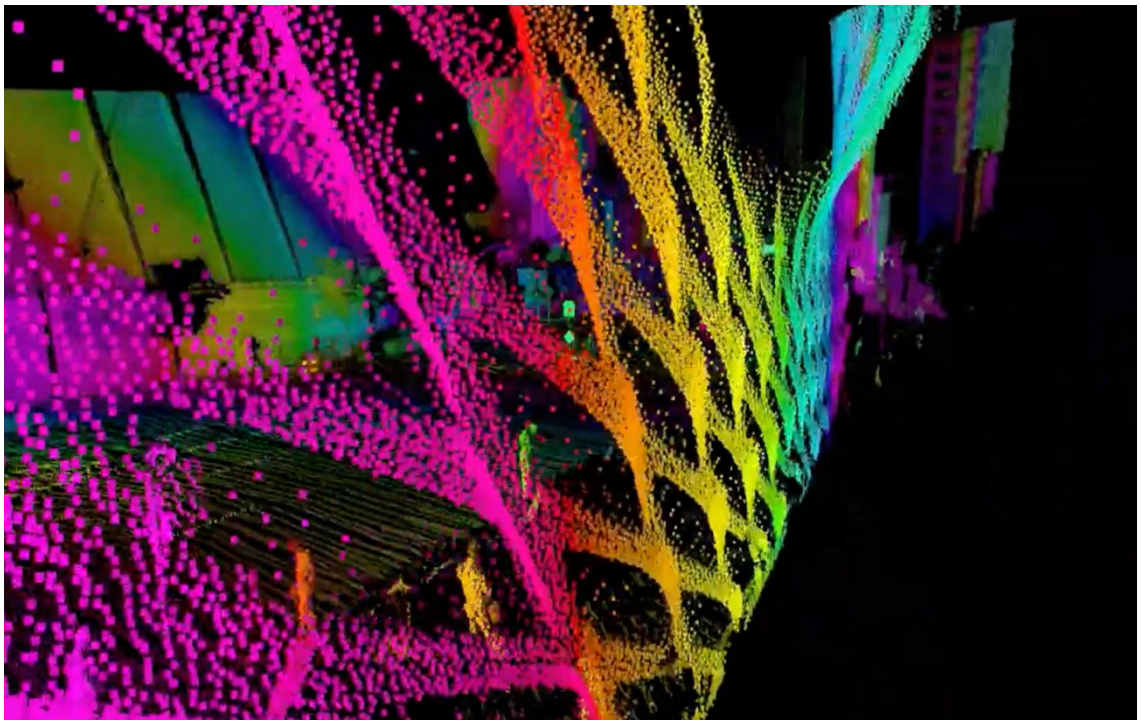


Figure 77 Sixth of a series of screenshot taken from: https://www.youtube.com/watch?v=8uMPqp_Xz5g last accessed 14/03/2024.

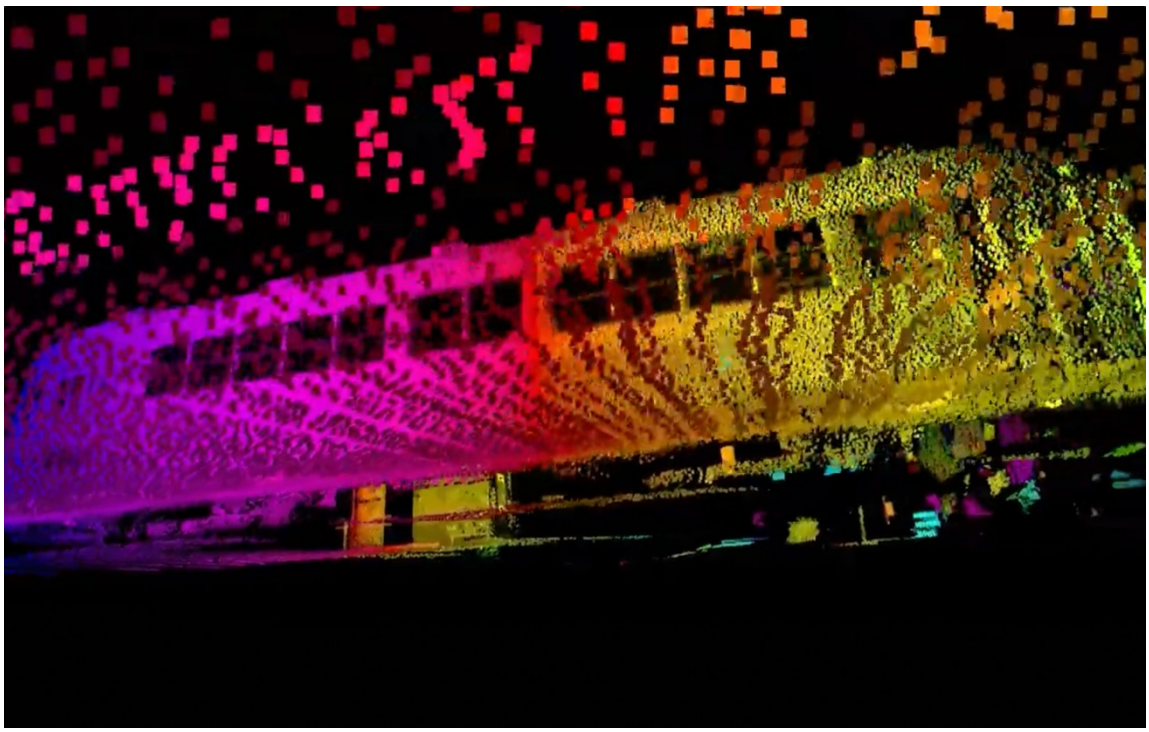


Figure 78 Seventh of a series of screenshot taken from: https://www.youtube.com/watch?v=8uMPqp_Xz5g last accessed 14/03/2024.

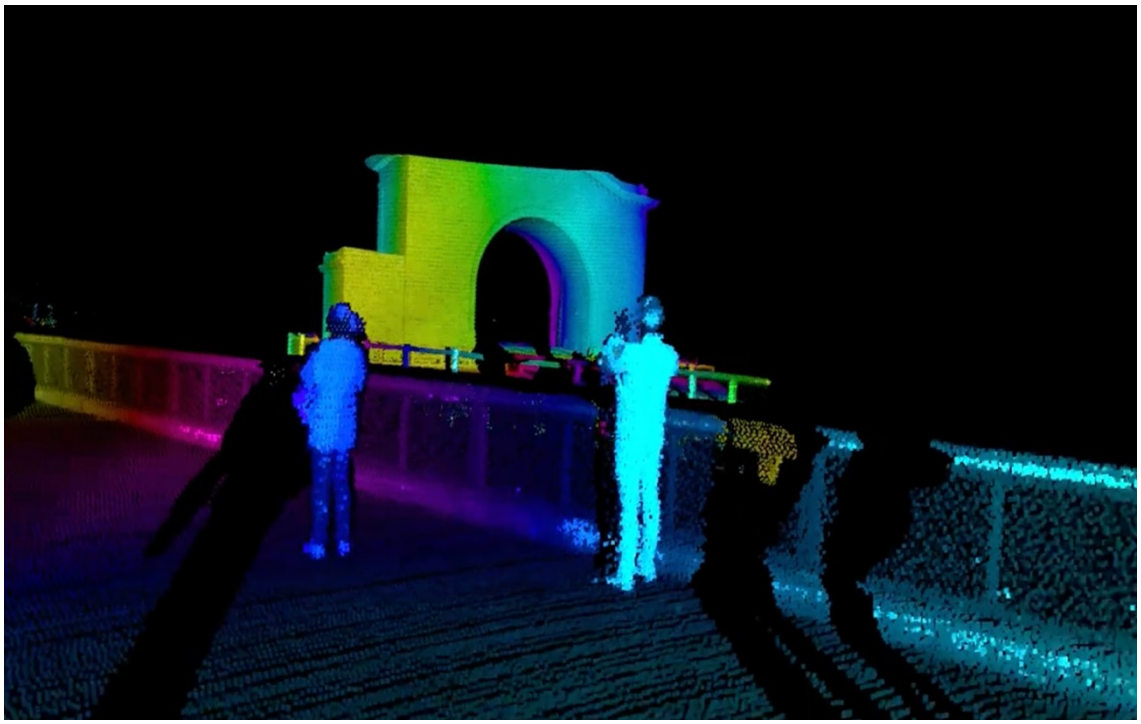


Figure 79 Eights of a series of screenshot taken from: https://www.youtube.com/watch?v=8uMPqp_Xz5g last accessed 14/03/2024.



Figure 80 Ninth of a series of screenshot taken from: https://www.youtube.com/watch?v=8uMPqp_Xz5g last accessed 14/03/2024.

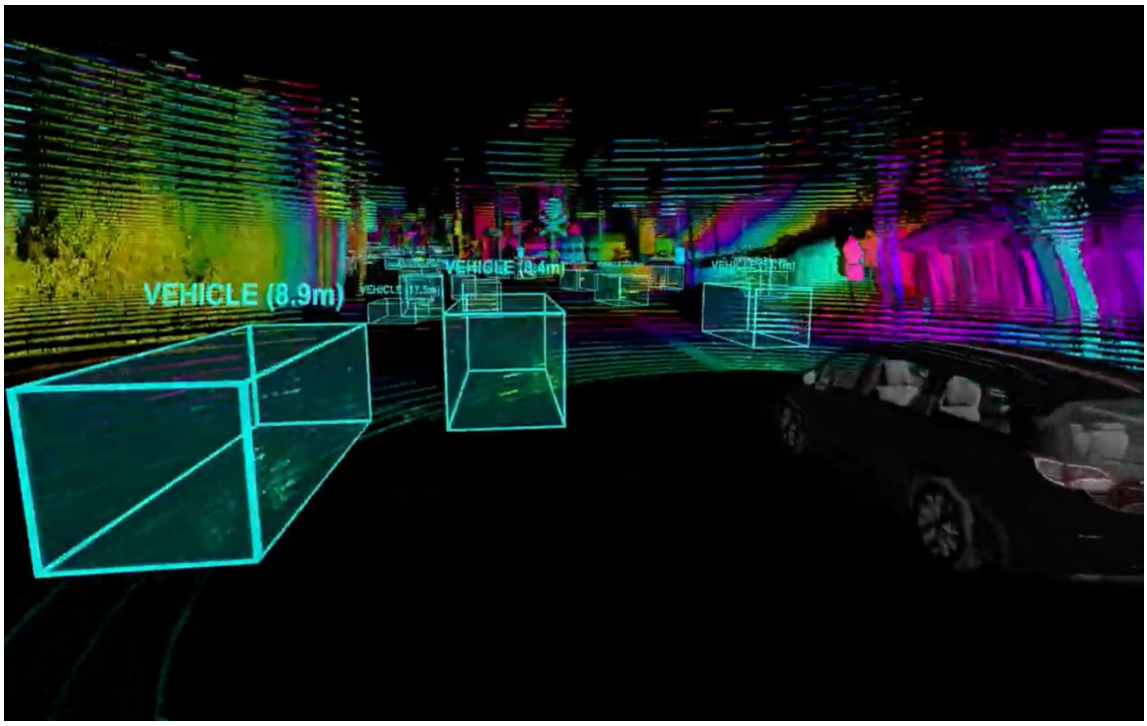


Figure 81 Tenth of a series of screenshot taken from: https://www.youtube.com/watch?v=8uMPqp_Xz5g last accessed 14/03/2024.

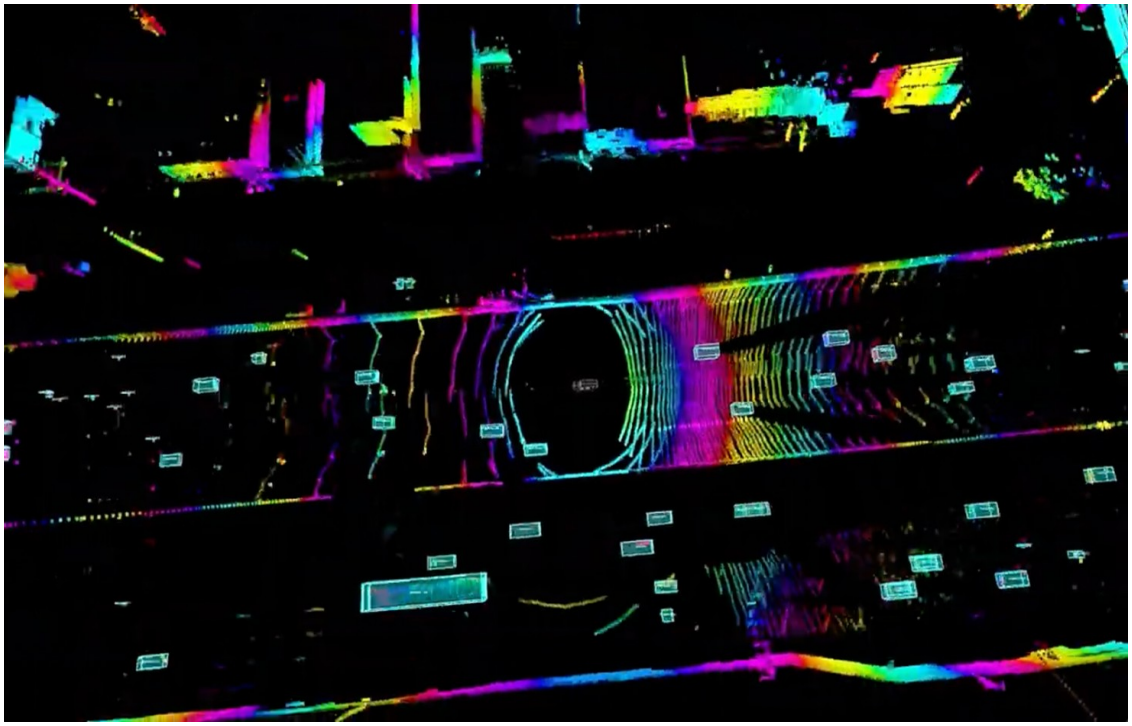


Figure 82 Eleventh of a series of screenshot taken from: https://www.youtube.com/watch?v=8uMPqp_Xz5g last accessed 14/03/2024.

Unlike traditional Renaissance paintings with a fixed central perspective (Farinelli, 1981:206; Farinelli, 2009:106-107), the Lidar point cloud offers a fluid and adaptable perspective. The viewer is removed from a fixed vantage point, and it becomes challenging to define who or what the subject of this machinic perception truly is. This video serves as a striking example of how Lidar technology can not only capture the physical world but also create surreal and immersive visual experiences that challenge our understanding of space and time.

Ouster is at the forefront of advancing Lidar technology by making it completely digital, eliminating moving or semi-moving components from the sensor architecture and relying on semiconductor materials for emitting and reading photons. This shift toward digital Lidar has several advantages, including cost reduction and size reduction of the sensor. Apple has also developed its own digital Lidar technology, which is contributing to the broader adoption of Lidar in various applications, including mobile devices (Luetzenburg et al., 2021; Teppati Losè et al., 2022).

One of the notable features of Ouster's Lidar technology is its ability to provide exceptionally clean and detailed point clouds. This capability makes it suitable for a wide range of applications, from mapping and digital twins in fields like archaeology, paleontology, to industrial applications in environments such as airports, warehouses, and mines. Lately, Ouster has also been collaborating with start-ups for canopy monitoring. Furthermore, Ouster's sleek chip design is well-suited for integration into automotive designs without disrupting the aesthetic lines of vehicles.

Ouster's YouTube channel features numerous videos showcasing their Lidar technology. These videos typically display point clouds with a color scale ranging from

purple to yellow. The scenes depicted include various streets and locations (see Figure 83). One notable video, titled "OS1-128 SLAM in San Francisco," is from two years ago and demonstrates real-time mapping and localization as a car travels through the streets of San Francisco (see Figure 84-86).

In this video, the road is observed from a bird's-eye view perspective, slightly slanted[24]. As the car moves forward, the surrounding landscapes transform in a smooth but somewhat artificial manner. Additionally, objects encountered along the way are depicted as trails of points, making them challenging to perceive as distinct objects but rather inferred through their point trails in motion. This video showcases the capabilities of Ouster's Lidar technology in mapping and real-time spatial awareness, however, watching the video in real-time, the images showcase a kind of haunting ephemeral quality that is hard to describe verbally[25]

[24] Studies around the specific viewing modalities of satellites and drones are Kurgan (2013), Kullmann (2016), Jackman (2022) and Jackman and Brickell (2022); however, as I will illustrate in this chapter and the next more specifically, the geometry of Lidar imaging is not volumetric.

[25] This could be seen as an instance of the dialectic between life, death, and the trace, from a Derridean perspective, and what kind of visuality testifies these nuances. See also Roberts, E., 2013. Geography and the visual image: A hauntological approach. *Progress in Human Geography*, *37*(3), pp.386-402.



Figure 83 Screenshot taken from https://www.youtube.com/watch?v=uAD9ObceNU8 last accessed 14/03/2024.

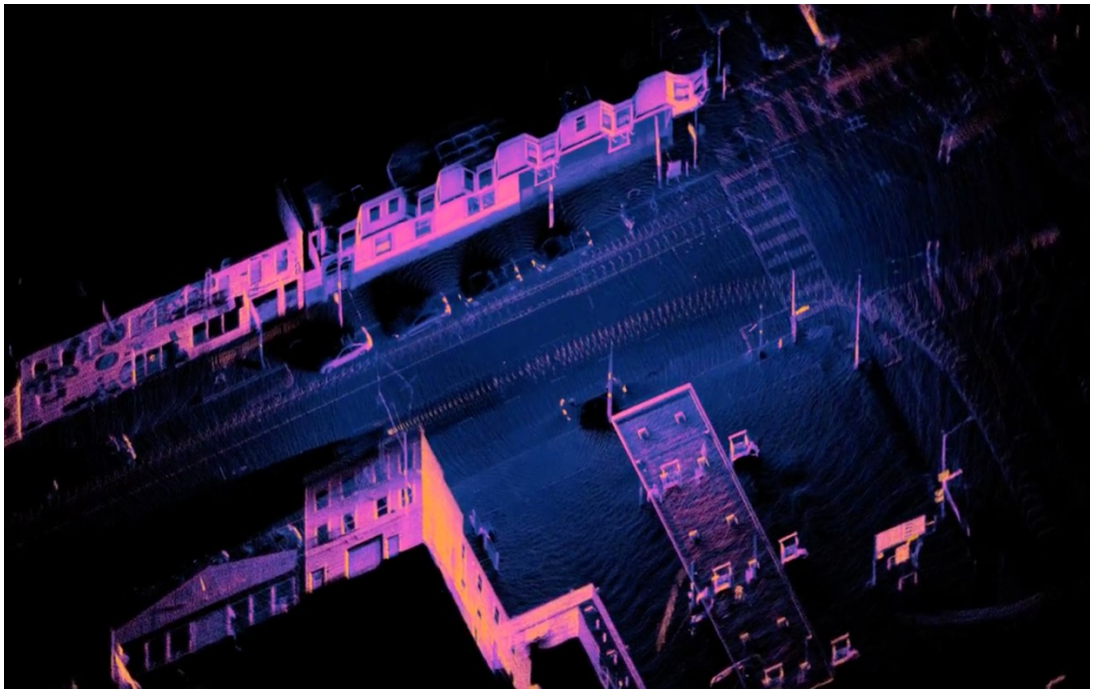


Figure 84 First Screenshot taken from https://www.youtube.com/watch?v=1XZt9u5Trh8 last accessed 14/03/2024.

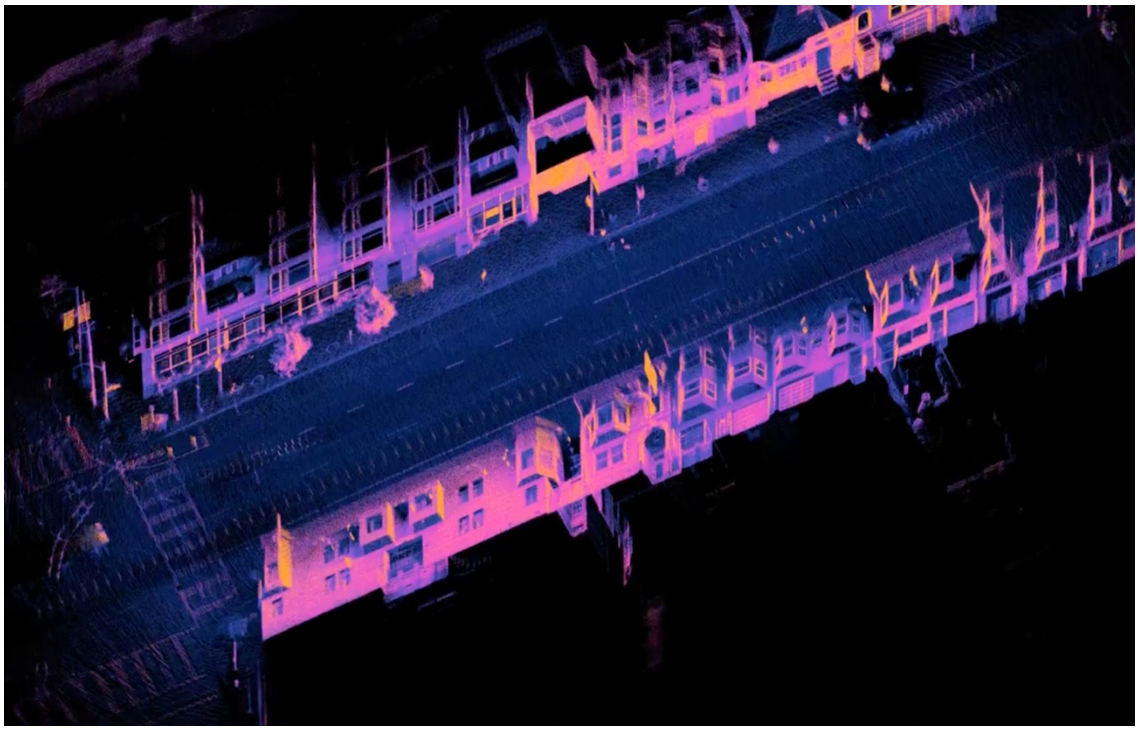


Figure 85 Second Screenshot taken from https://www.youtube.com/watch?v=1XZt9u5Trh8 last accessed 14/03/2024.

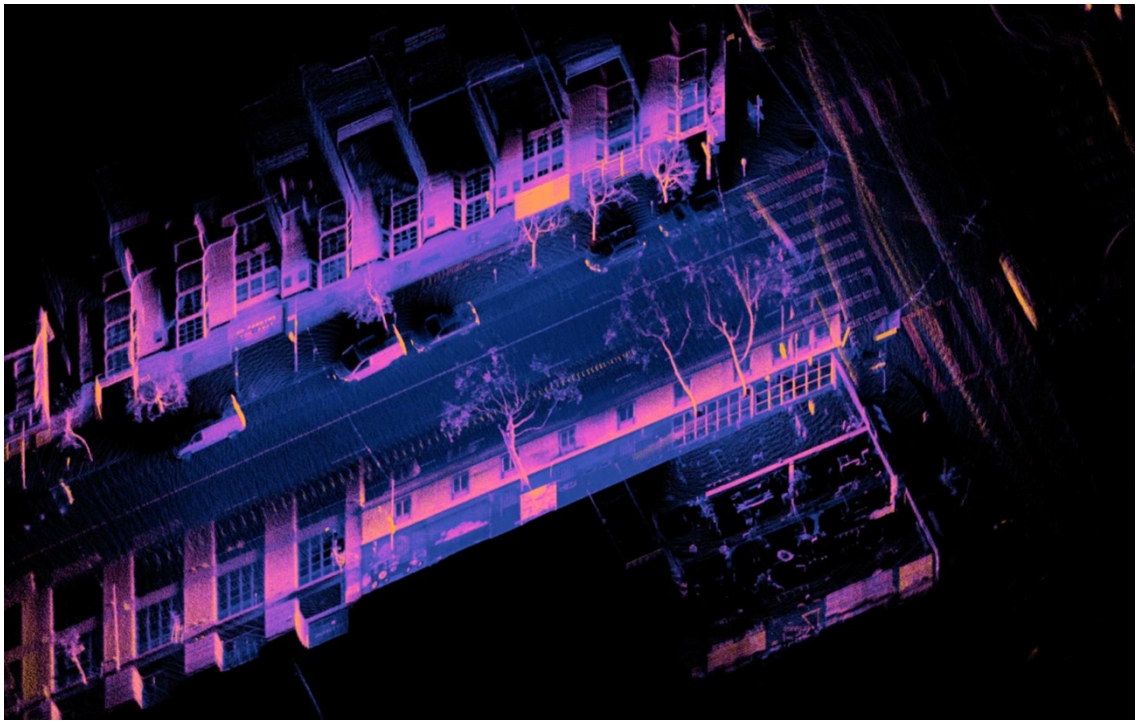


Figure 86 Third Screenshot taken from https://www.youtube.com/watch?v=1XZt9u5Trh8 last accessed 14/03/2024.

Quanergy, like the competitors, proposes videos that showcase different perspectives and a somewhat haunting quality to the environment being pictured (see Figure 87-92).

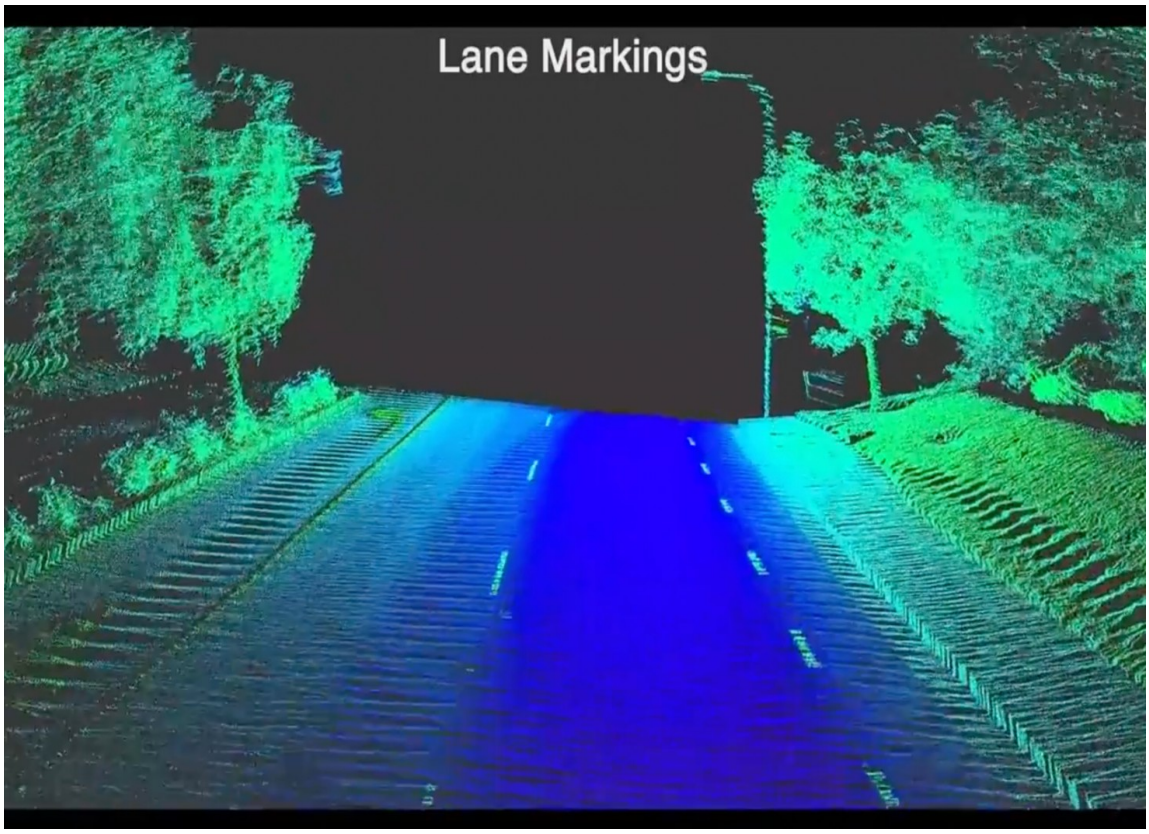


Figure 87 First screenshot taken from https://www.youtube.com/watch?v=u3clsAKrZuk available on Quanergy channel. Last accessed 14/03/2024.

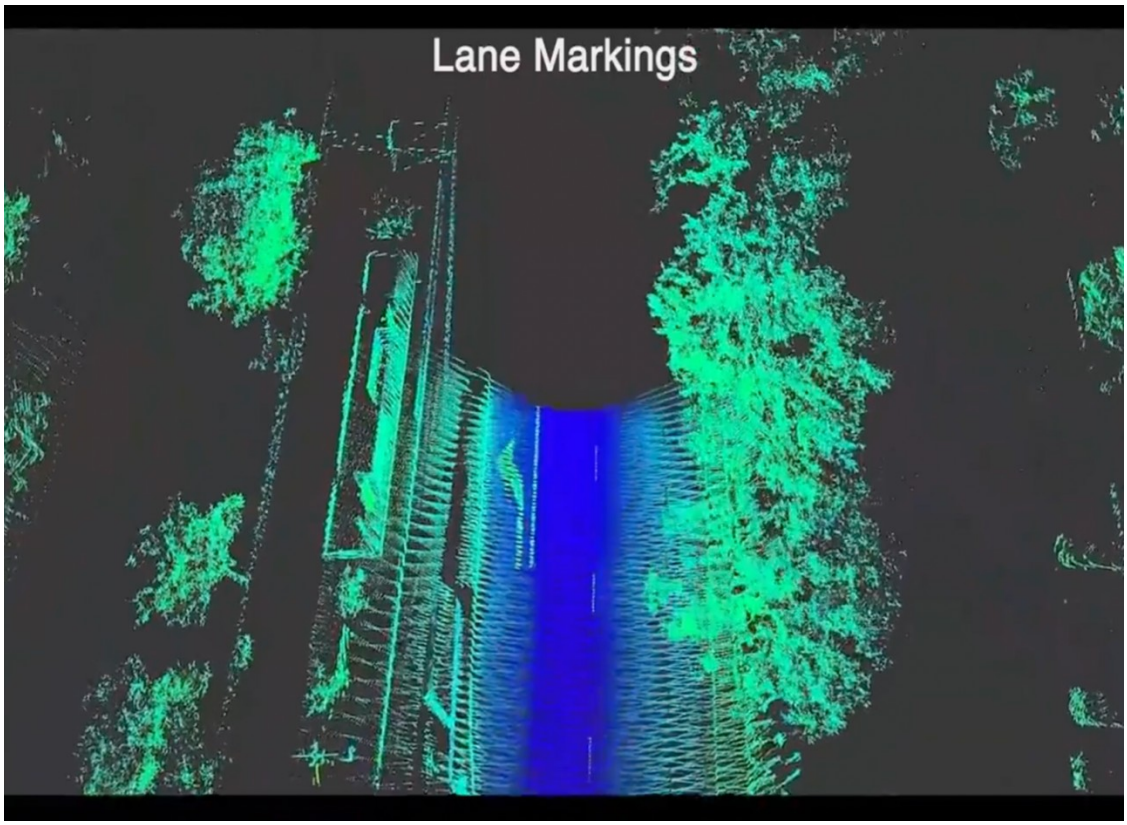


Figure 88 Second screenshot taken from https://www.youtube.com/watch?v=u3clsAKrZuk last accessed 14/03/2024.

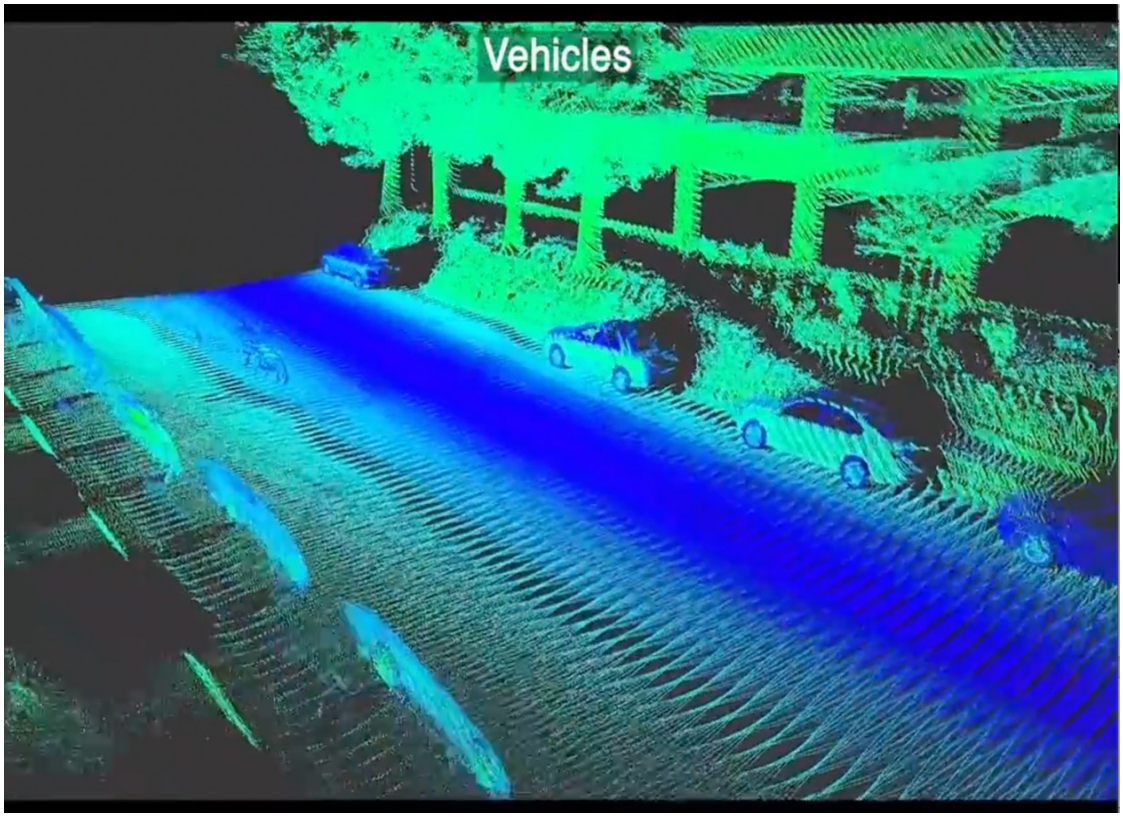


Figure 89 Third screenshot taken from https://www.youtube.com/watch?v=u3clsAKrZuk last accessed 14/03/2024.

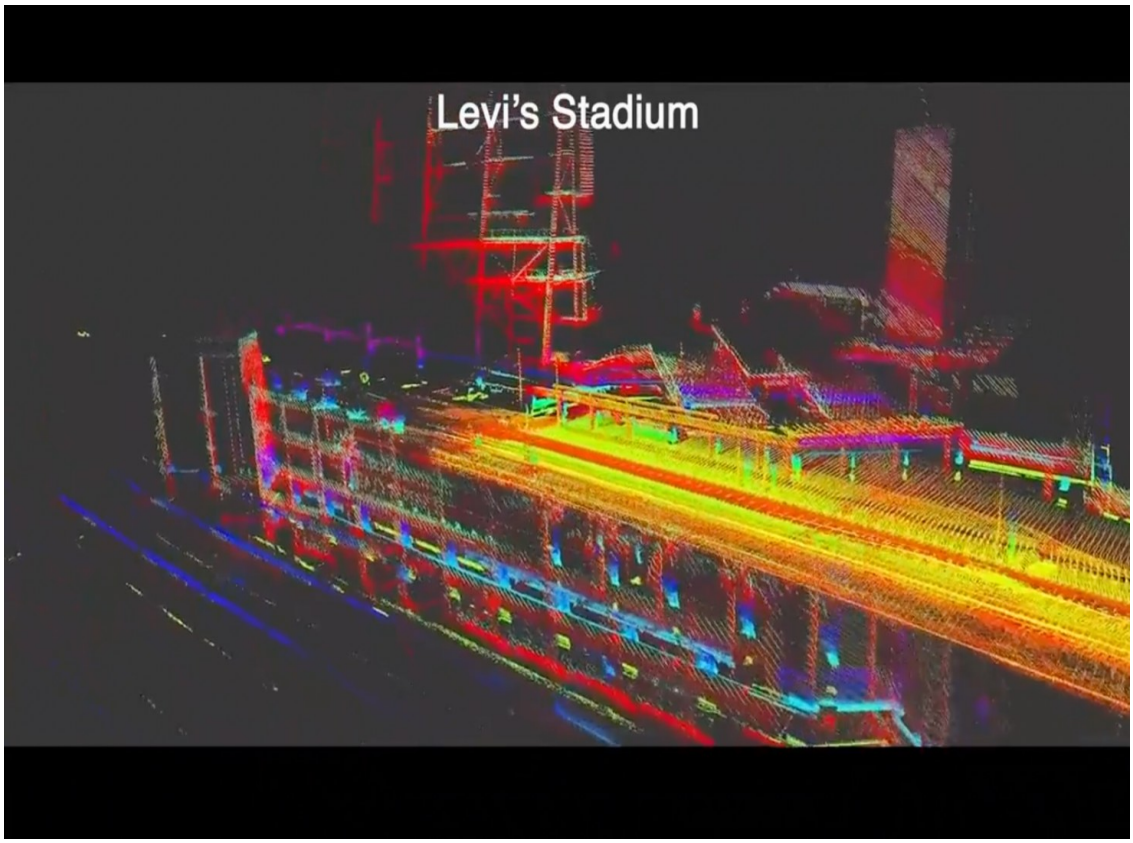


Figure 90 Fourth screenshot taken from https://www.youtube.com/watch?v=u3clsAKrZuk last accessed 14/03/2024.

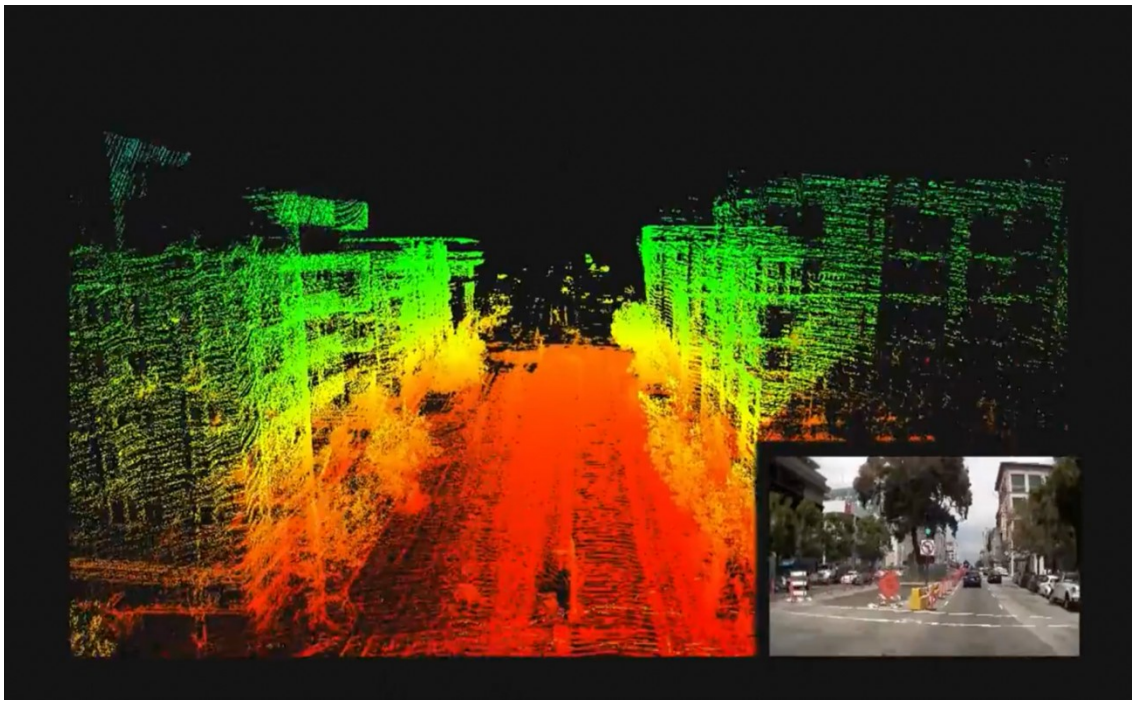


Figure 91 First screenshot taken from https://www.youtube.com/watch?v=TPMFMzxy5KE last accessed 14/03/2024.

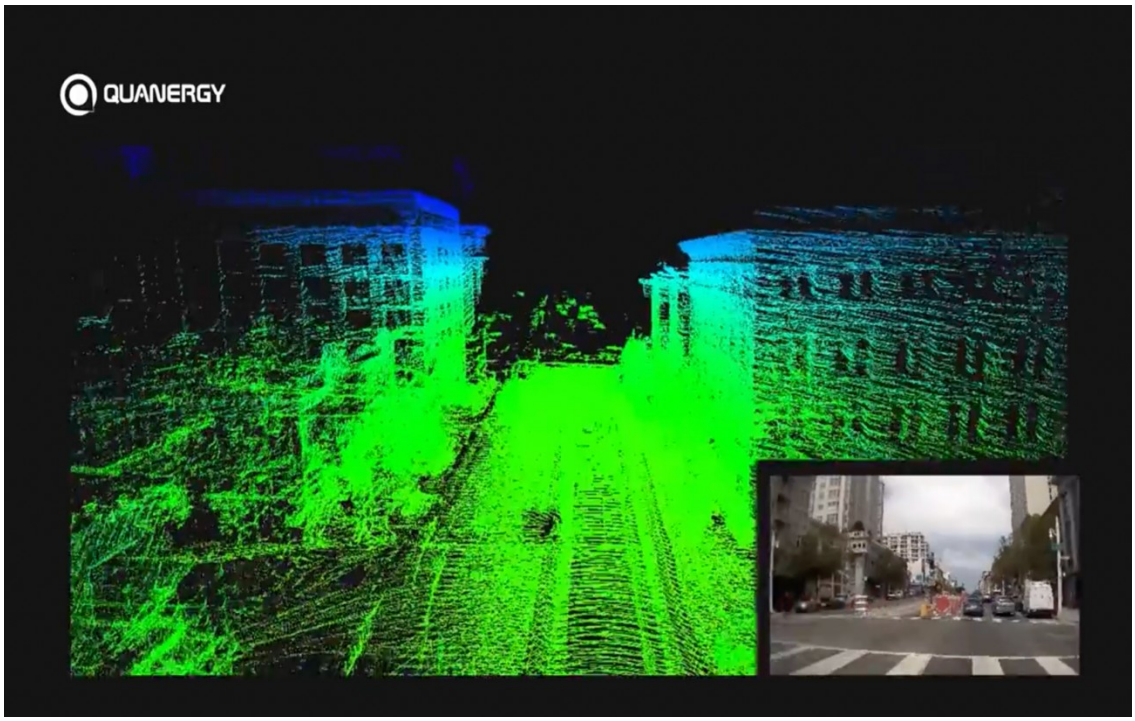


Figure 92 Second screenshot taken from https://www.youtube.com/watch?v=TPMFMzxy5KE last accessed 14/03/2024.

Velodyne, one of the pioneers in the development of Lidar sensors and software systems, has evolved its marketing approach over the years. Initially known for its pioneering work in Lidar technology, the company's marketing strategy has shifted in recent years, focusing less on promoting the technology itself and more on showcasing its various partnerships and applications.

On Velodyne's YouTube channel, you can find videos featuring engineers, experts, and partners discussing how the company's technology contributes to safety, particularly through partnerships such as the one with Mothers Against Drunk Driving. These videos often include excerpts from speeches, interviews, and panel discussions, where the company's technology is explained, and its applications are highlighted.

Since a patent dispute that the company went through, Velodyne's video presentations have increasingly emphasized industrial automation, traffic management for smart cities,

and last-mile robotics. These applications are considered crucial for improving safety and efficiency in various domains.

Velodyne's distinct visual style for Lidar representation is characterized by a blue-colored backdrop filled with surfaces of three-dimensional objects shaded in various shades of blue and green. The Lidar scanning patterns, marked by concentric circles, are often visible around the location of the sensor. Sometimes, objects detected by the Lidar are enclosed in semantic boxes in these visualizations (see Figure 93-96).

One specific video titled "Velodyne Lidar's Intelligent Infrastructure Solution" introduces the concept of the Intelligent Infrastructure Solution (IIS), a platform designed to extract traffic data and enable analytics. This platform is presented as a groundbreaking approach to smart city technology, and the video combines cinematic footage with point cloud representations to illustrate its capabilities (see Figure 97).

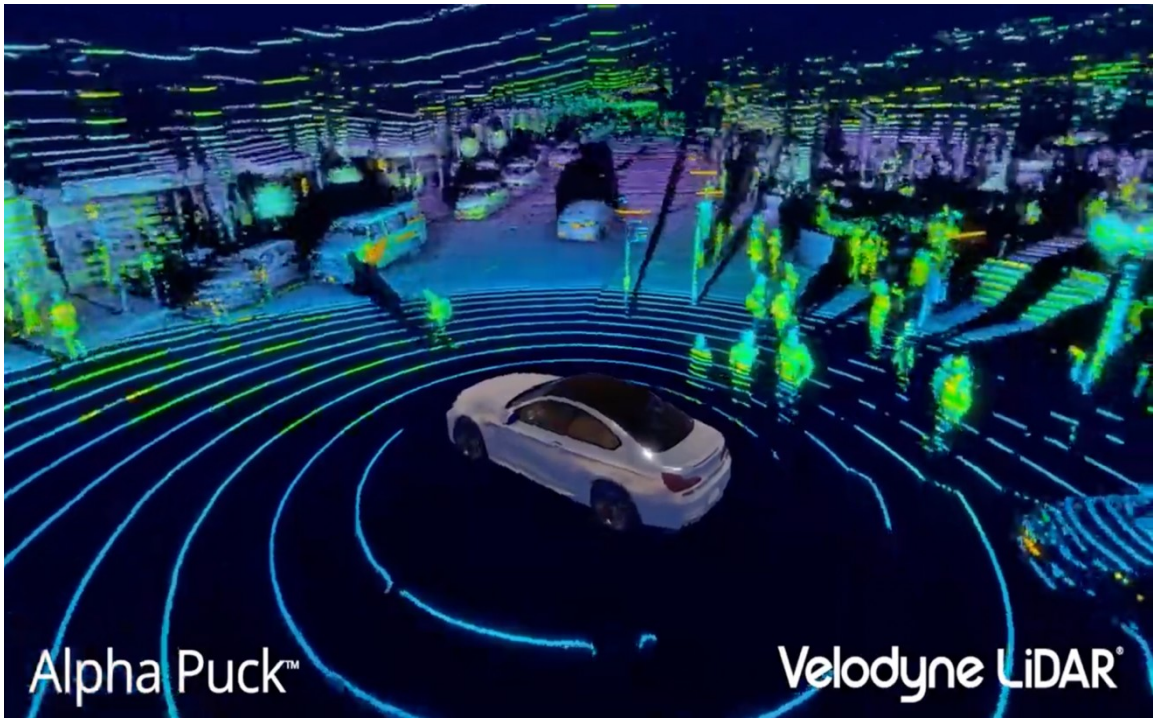


Figure 93 First screenshot taken from https://www.youtube.com/watch?v=JWdiWUOAVYU last accessed 14/03/2024.

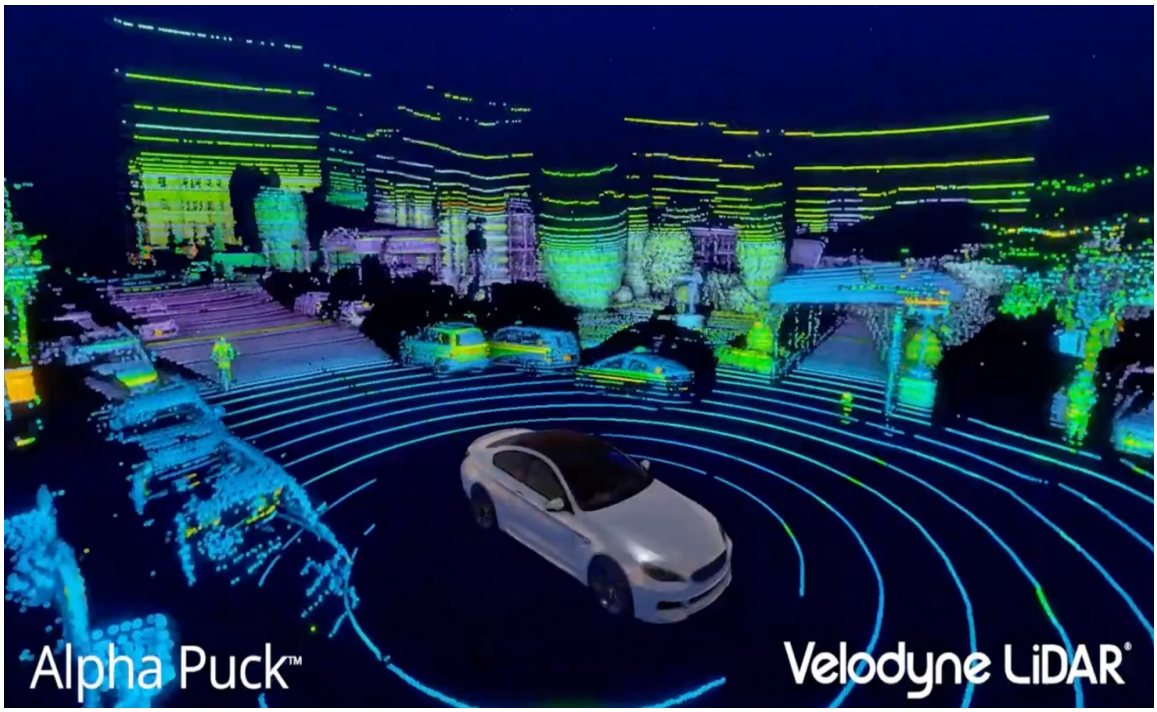


Figure 94 Second screenshot taken from https://www.youtube.com/watch?v=JWdiWUOAVYU last accessed 14/03/2024.

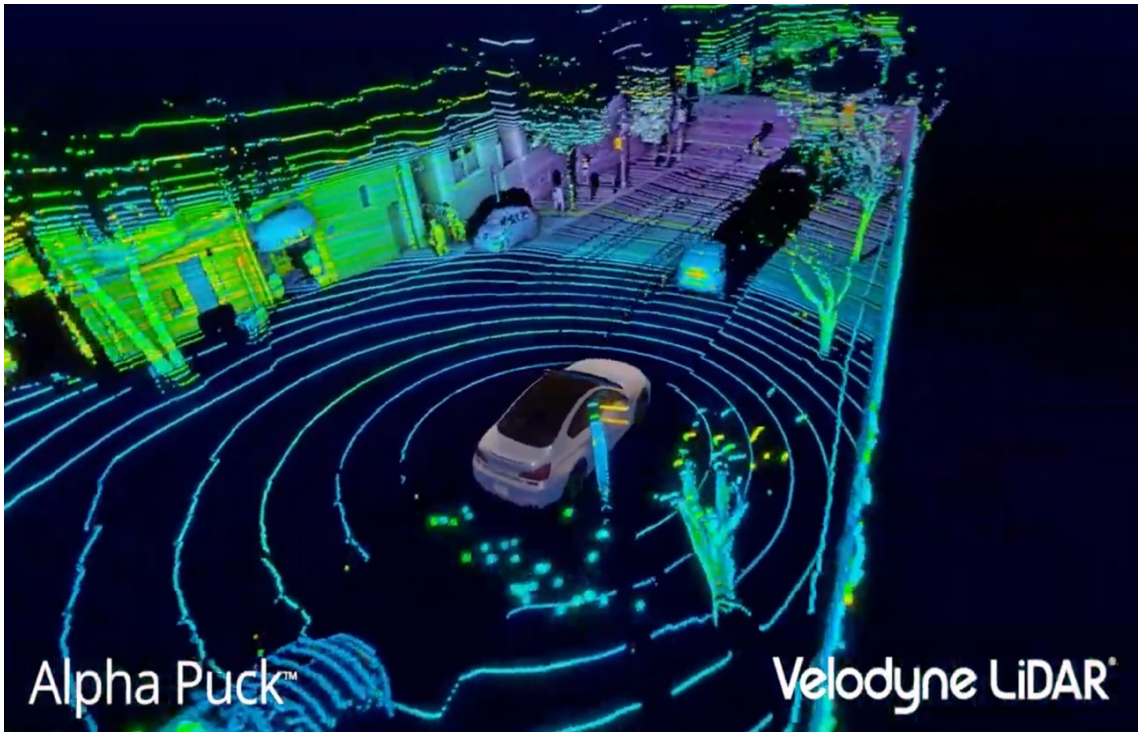


Figure 95 Third screenshot taken from https://www.youtube.com/watch?v=JWdiWUOAVYU last accessed 14/03/2024.

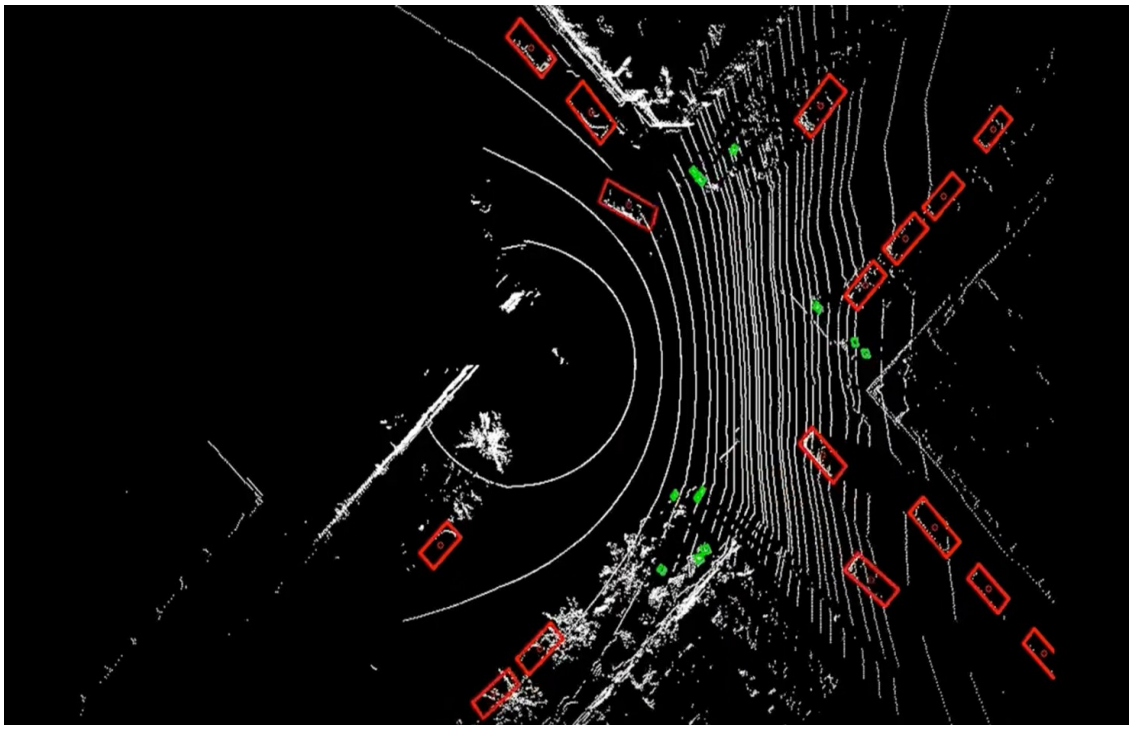


Figure 96 Screenshot taken from https://www.youtube.com/watch?v=wlFcLqbjt4g last accessed 14/03/2024.

Pony. Ai, co-located in the USA and China, appears to take a practical and transparent approach to showcasing its autonomous technology. One of the notable videos from this company is a six-hour drive of an autonomous truck, presented without any editing or cuts. This lengthy video provides an authentic look at how the system operates in complex real-world scenarios.

In addition to the full-length video, there is a shorter six-minute version that offers highlights of the autonomous truck's operation. This shorter video uses a tripartite split screen to present different perspectives. On the left side, there is a bird's-eye view of the vehicle navigating through the point cloud data. The right side is divided into two parts: the top portion shows camera footage of the steering wheel, demonstrating that it is not being touched by a human driver, and the bottom portion provides a subjective view of the road from the perspective of the truck.

An interesting aspect of this company's approach is that they do not typically display the point clouds on their own. Instead, they choose to integrate them into a simulated road environment, complete with a 3D rendering of the autonomous vehicle. The point cloud data representing buildings and vegetation is projected onto this simulated backdrop (see Figure 97 and 98).

This practical and transparent approach to presenting their autonomous technology may be intended to provide viewers with a clear understanding of how the system operates in real-world conditions. By integrating point cloud data into a simulated road environment, the company may be aiming to make the technical processes more accessible and comprehensible to a broader audience.

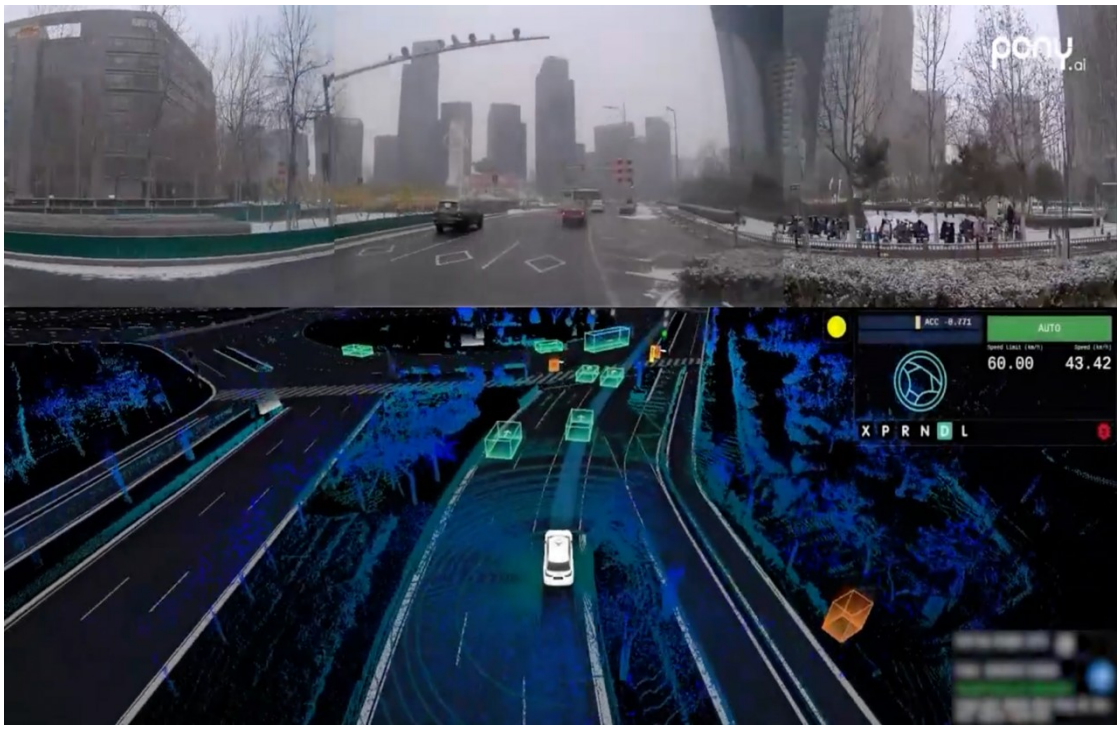


Figure 97 First screenshot taken from https://www.youtube.com/watch?v=ZWvqanxc3nM last accessed 14/03/2024.

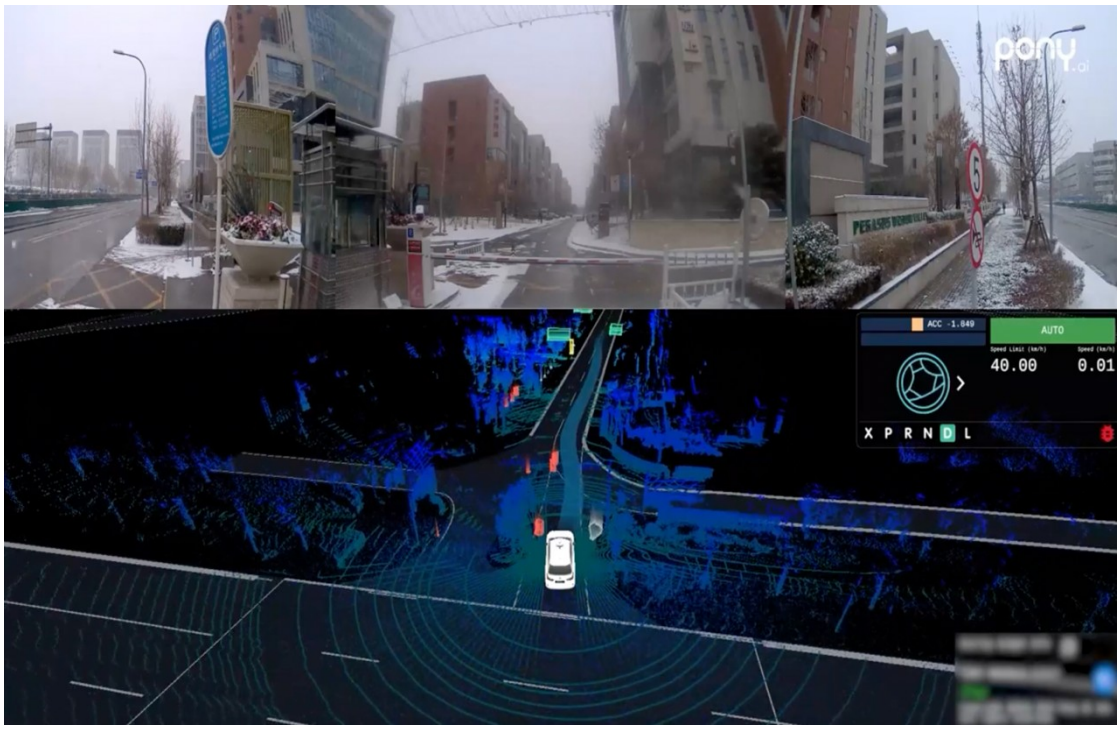


Figure 98 Second screenshot taken from https://www.youtube.com/watch?v=ZWvqanxc3nM last accessed 14/03/2024.

6.7 Time and Velocity

Aeva also emphasizes their 4D localization capability, where the fourth dimension is time. In one video, the system enters a tunnel, and the camera view shifts to a small square in the top-right corner, displaying the rest of the road as a point cloud with colorful representations (see Figure 99). This presentation highlights the temporal dimension as the car transitions through different environments.

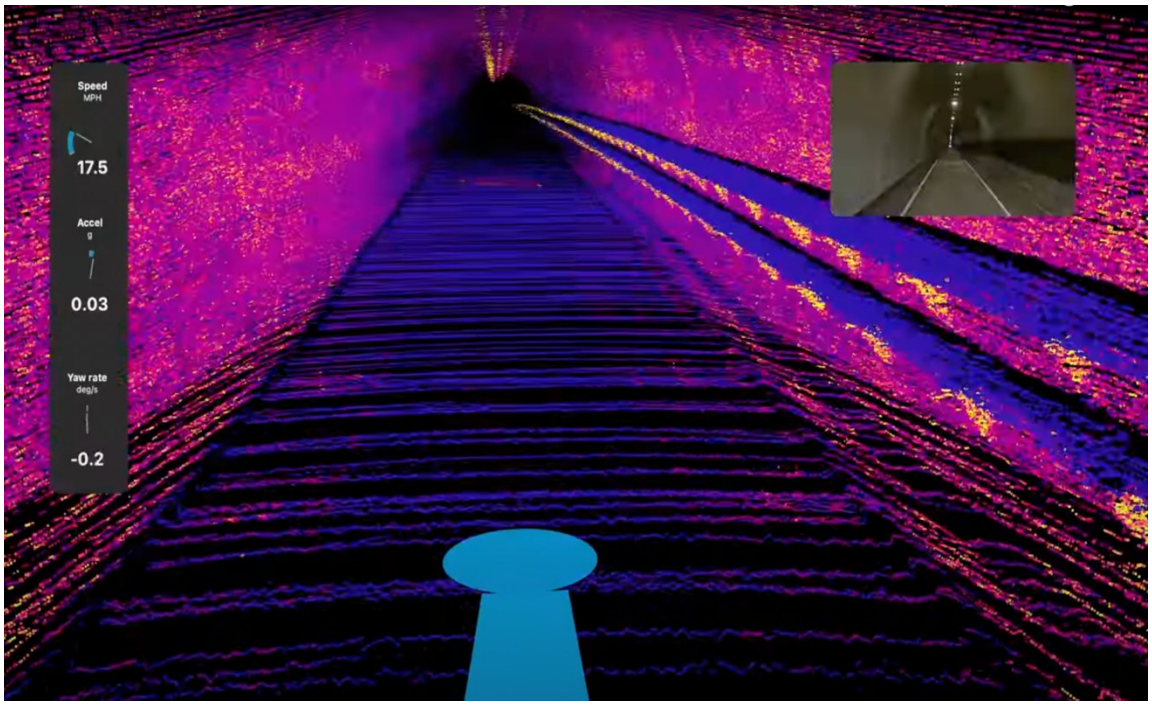


Figure 99 Screenshot taken from https://www.youtube.com/watch?v=vV9wtUBsCwo last accessed 14/03/2024.

In another video, the headers suggest that the fourth dimension of time is manifested in the recognition of object velocities in real-time. The point cloud displayed in this video is in grayscale, with objects color-coded in red or yellow and semantically enclosed within red boxes. The dimension of time is intrinsic to Lidar technology, as it relies on measuring the time it takes for reflected light to return to the receiver. This time data, combined with angle and distance measurements, allows the system to place points accurately in three-dimensional space.

However, it's important to note that the dimension of time also involves considerations of latency, including the time it takes for the laser to emit pulses, the computing system to process data, and the creation of points within a grid. Reducing latency is a significant technological challenge in achieving virtual simultaneity. Aeva's specific hardware and software architecture decisions play a crucial role in how they apprehend and represent space through time, which will be explored further in the next chapter.

One of the central themes in Luminar's video storytelling is "proactive security." This concept highlights the idea that autonomous vehicles should not only mitigate the impact of potential accidents but should also use data to prevent accidents from happening in the first place. This theme is explored in various ways, including historical comparisons (such as the introduction of safety belts), and interviews with drivers expressing reticence towards new safety technologies. Luminar ties this central idea of safety, already encountered in the previous chapter, to the idea that the car needs to stop in front of its obstacle “in time”. The concept of time is here connected to decisional speed. A similar narrative of time is deployed by AEye: the main discursive element that sustains Lidar development is once again safety, Lidar technology enables decision-making in situations in which “milliseconds count” (see Figure 100).

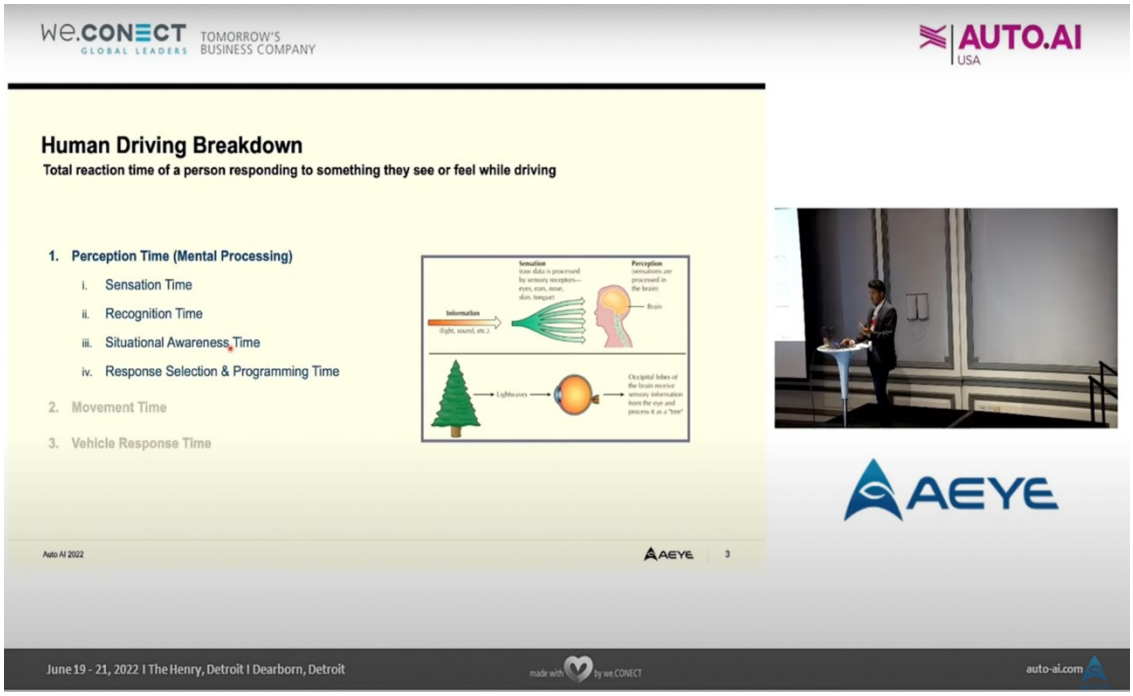


Figure 100 Screenshot taken from https://www.youtube.com/watch?v=PwWeH0cI_gA last accessed 14/03/2024.

Velodyne favors highlighting how a real-time stream of data is necessary for robotic navigation, but doesn't connect it to speed, favoring spatial features of range and data accuracy.

6.8 Colors between algorithmic and realist aesthetics

I contend that color choice is intentional in the construction of the preferred aesthetics of each and every brand. For instance, Ouster, before its rise to success, showcased the same color choice of Quanergy (see Figure 101).

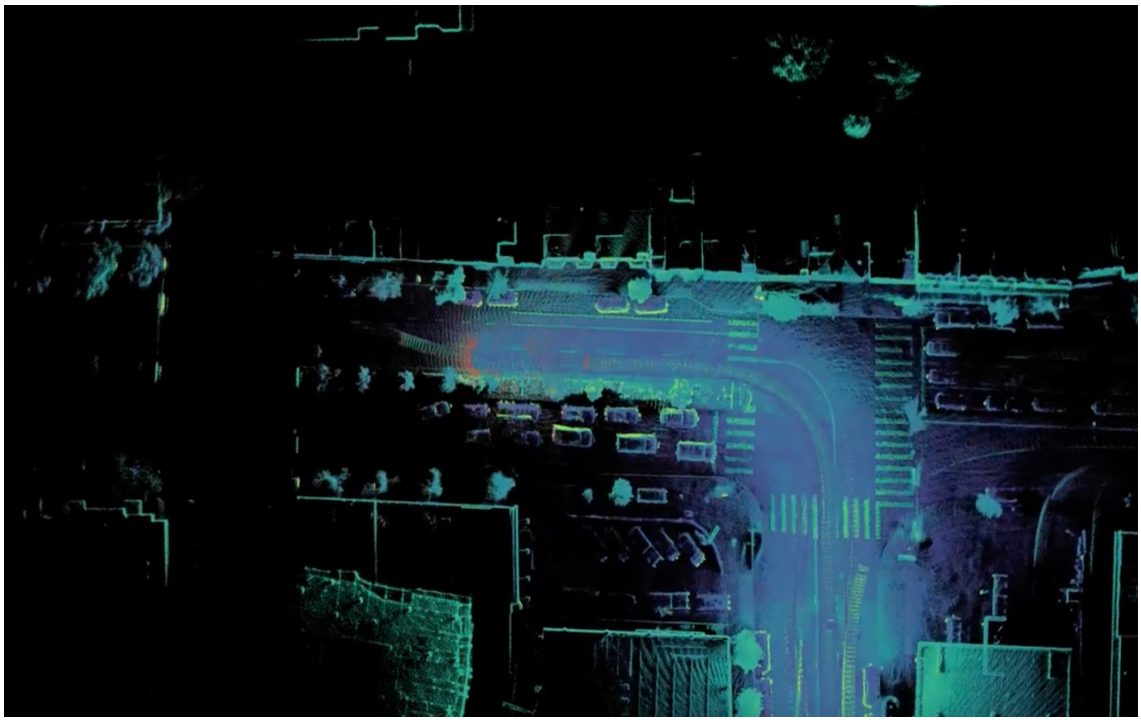


Figure 101 Screenshot taken from https://www.youtube.com/watch?v=koYBqeBdBec from Ouster's channel, last accessed 14/03/2024.

In spite of deploying colors from the same spectrum, the animated visualizations produced by Ouster and showcased in the video present a completely different perspective from those of Quanergy. And the way the data appears on the screen is also different, because of the different perspective. In the Ouster video the car and the other moving

objects that it encounters are not clearly visible; they appear as a sort of orange segment that moves through the blue data, living a warmer trail behind.

The other companies presented in this sample prefer a similar aesthetic, based on RGB colors on a dark screen, motivated by different representing factors – for example, Aeva bases part of its color layering based on their desire to showcase how spatial relationships in their visualization are enmeshed with velocity measurement. Among those choosing a so-called RGB aesthetics[26], Luminar stands out because of the rainbow organization of colors. As highlighted in the previous chapter, this color choice might testify to an adherence to latest trends in the cyber subculture.

Among the companies, Innoviz's approach to displaying the features of their Lidar technology includes the use of a tripartite split screen, similar to other companies. As seen above, this screen division provides viewers with multiple perspectives: the left portion shows a top-down view of the sensor's range, the top portion displays a camera view from the car's subjective perspective, and the bottom portion showcases a point cloud generated by the sensor.

A notable characteristic of Innoviz's point cloud representation is its distinctive coloring. While earlier point clouds from various companies typically used black backgrounds with objects colored in red, green, and yellow, Innoviz has chosen a different color scheme. Their recent point clouds feature a brownish tint, ranging from deep maroon to yellowish tones, creating a palette that evokes a sense of naturalness. This departure from the traditional algorithmic colors (black, white, and RGB) adds a touch of realism to the

[26] Cubitt (2015:111-151) provides a complete history of color, the science and the techniques behind it, from the ancient oil master to the standard of RGB in digital images, passing through an earlier attempt at Technicolor. For a simpler outlook on these matters, rooted in practical aims, see Stone, 2016.

visualizations. It mimics the idea that shadows in nature are not pure black, contributing to a more natural appearance.

The content of Innoviz's videos further reinforces this sense of naturality. Their videos often depict scenes of people engaged in various everyday activities, such as picnicking, helping pedestrians cross the street, or children playing in a yard. These urban scenes are presented with a vibrant and lifelike quality, highlighting the presence of people going about their lives. The contrast is stark, comparing the moving images to those of the competitors, which often depict a city completely devoid of humans. As shown above, even Luminar's images, which present an abundance of people engaging in different activities on the sidewalks and in square, become somewhat of a rainbow colored component of the many elements that compose the adornments of the metropolitan environment.

Innoviz's videos also offer a glimpse into the challenges of perceiving the world through the eyes of a car equipped with Lidar technology. As the perspective shifts, zooms in and out, and pans across the scenes, the points that compose objects, people, and the ground become scattered and fragmented. These points take on different shades of brown, resembling scattered stars in the night sky. The abundance of points, each representing a distance measurement, can be challenging to organize when they no longer resemble coherent surfaces.

This observation raises an essential point about Lidar technology: while the data collected are inherently three-dimensional, they are projected onto a two-dimensional screen for human interpretation. The screen serves as the interface between the two-dimensional logic of maps and the three-dimensional logic of cyberspace. The

mathematical properties and implications of these different geometries, especially in terms of how they relate to human perception and understanding, will be further explored in the next chapter.

6.9 A visualization of flows

Quanergy's approach to Lidar technology differs from some of its competitors, as the company focuses not only on autonomous driving but also on various other applications such as HD mapping for smart cities, traffic management, agriculture, and the industrial sector, including automotive applications. However, in recent years, Quanergy has increasingly concentrated on surveillance applications like crowd detection and tracking.

Quanergy's videos provide an intriguing contrast to their website, which may appear relatively plain. These videos showcase various applications of their Lidar technology. One video, titled "Quanergy CORTEX Intro," employs a unique visualization approach (see Figure 102, 103 and 104). It begins with a split screen, with the right portion showing a group of people descending a staircase. The footage appears to be captured by an infrared camera, though it is somewhat challenging to discern the identities and activities of the individuals. Some wear glasses, while others do not, and they all seem to be dressed similarly, with badge-like items hanging from their necks.

On the left side of the screen, an overhead view displays each person as a single point encircled by a larger one. As they move, each point leaves behind a continuous yet erratic line, tracing their paths. This visualization technique is then applied to different scenarios in subsequent scenes. While the specific locations are not always recognizable, the third

scene resembles an intersection, and the fourth appears to depict a line of cars in a parking lot.

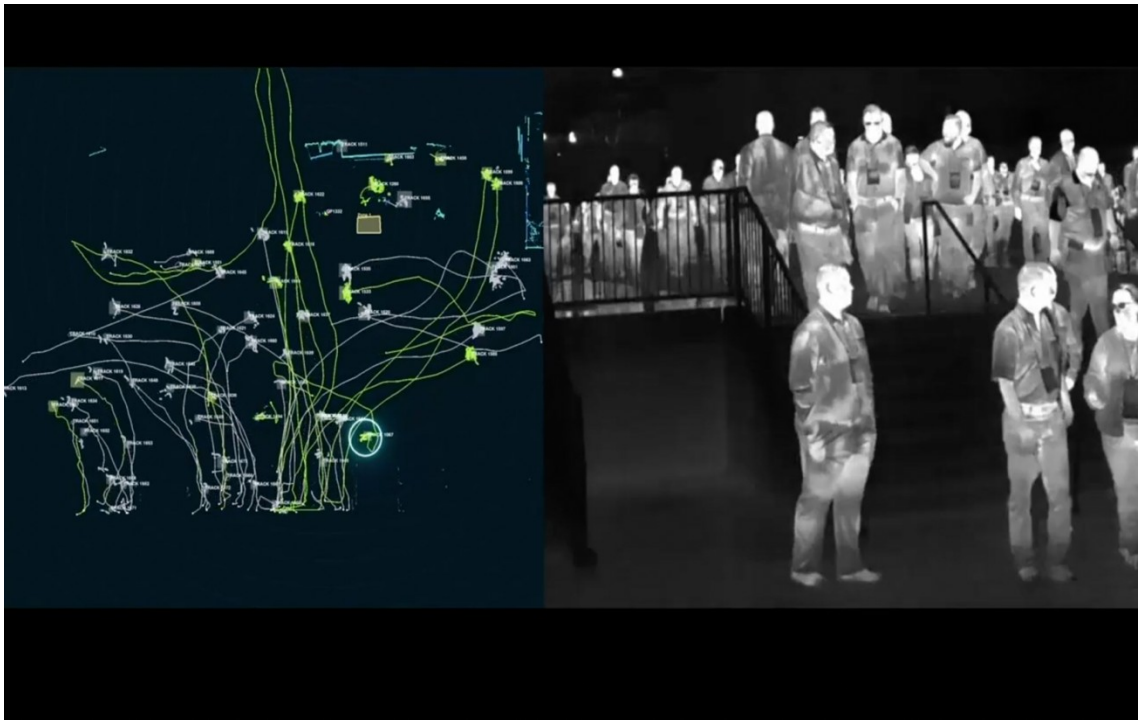


Figure 102 Screenshot taken from the Quanergy YouTube channel video https://www.youtube.com/watch?v=nJMbxCcMLpI. Last accessed 14/03/2024.

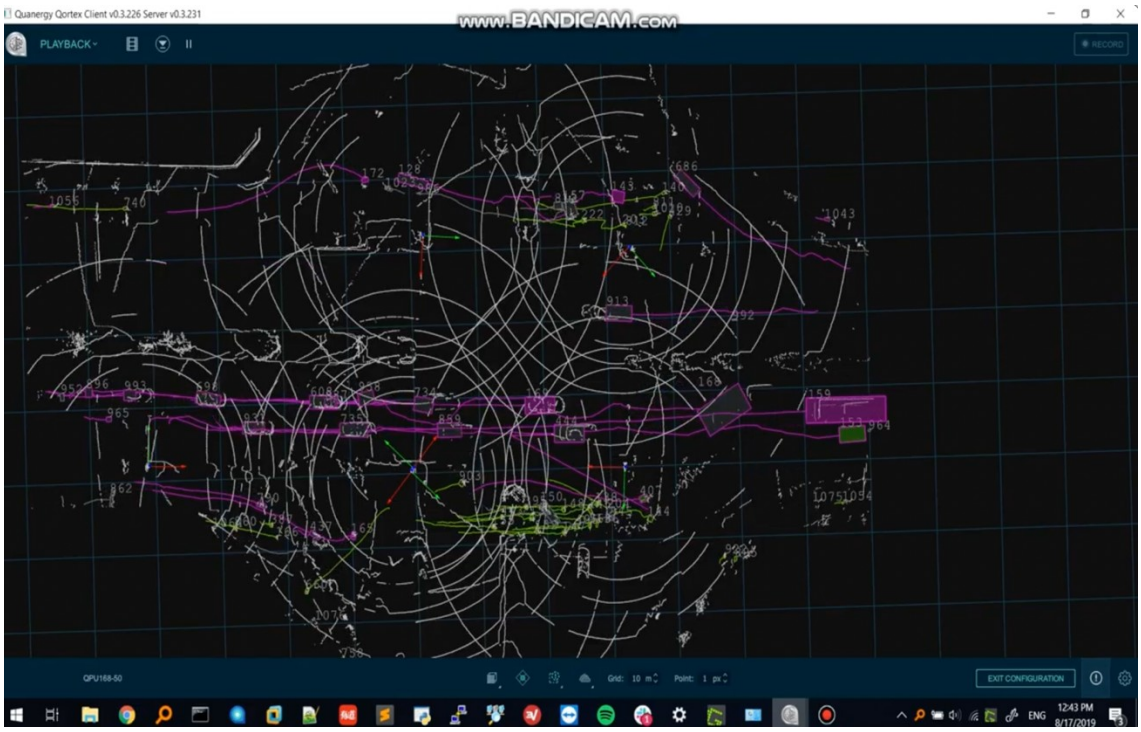


Figure 103 Second screenshot taken from the same video at a later point. Last accessed the same day.

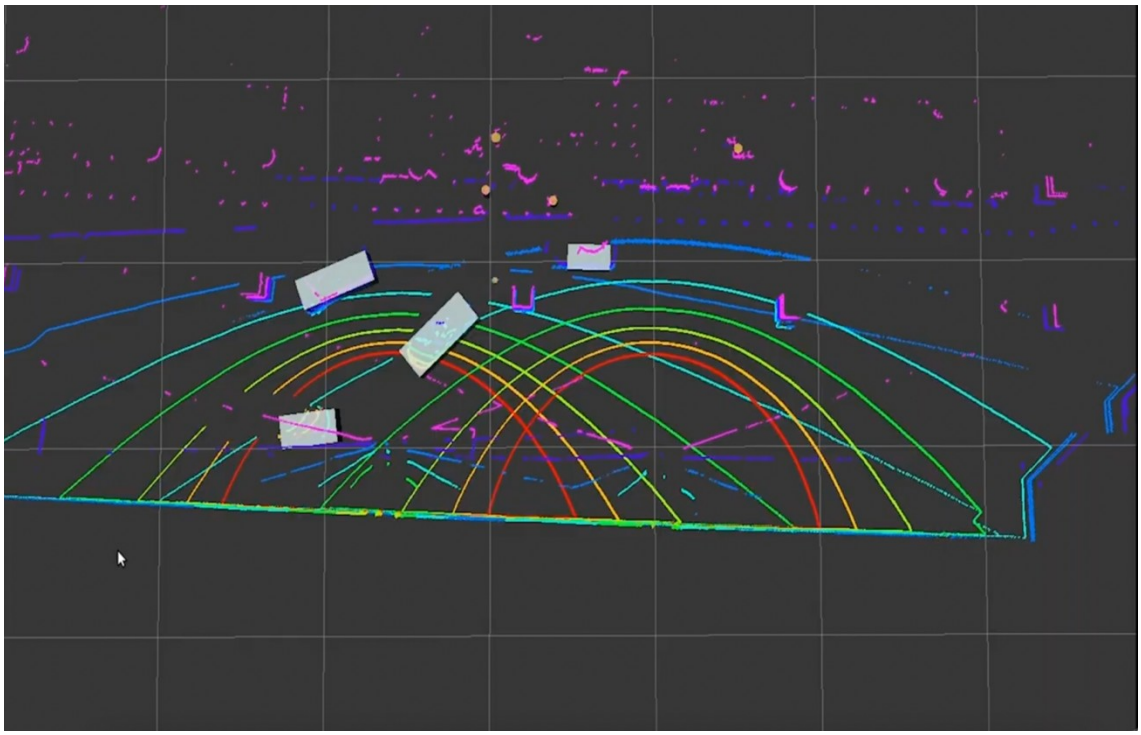


Figure 104 Third screenshot taken from the same video at a later point. Last accessed the same day.

This way of visualizing objects and their interactions, emphasizing their paths, raises questions about surveillance through the monitoring of movement patterns. It appears to be an attempt to bring order to the unpredictability and complexity of urban flows by imposing a grid-like structure on the chaotic nature of these phenomena. The ambiguity surrounding surveillance and the tracking of individuals in urban spaces is evident in this visual representation[27].

In a similar vein, in another AEye video titled "ITS perception demo with Seoul Robotics," the visual rendering features a charcoal gray background with faint grid lines, and a mustard yellow boundary defines the area of interest (see Figure 105). Inside this area, a grayscale point cloud illustrates a parking area with cars and stylized human figures enclosed within green cylinders. These figures appear to perform a peculiar

[27] For a commentary on the disciplining of turbulence see Cubitt (1998:129-131). For a commentary on the concept of flow within time-geography see Sutherland (2018).

choreography, leaving neon green trails behind them. The presenter explains the system's capability for pedestrian classification and tracking, emphasizing its value in surveillance applications. Indeed, when an entity is calculated to have spent more than seven seconds in the same spot, the system automatically emphasizes that area as “of interest”.

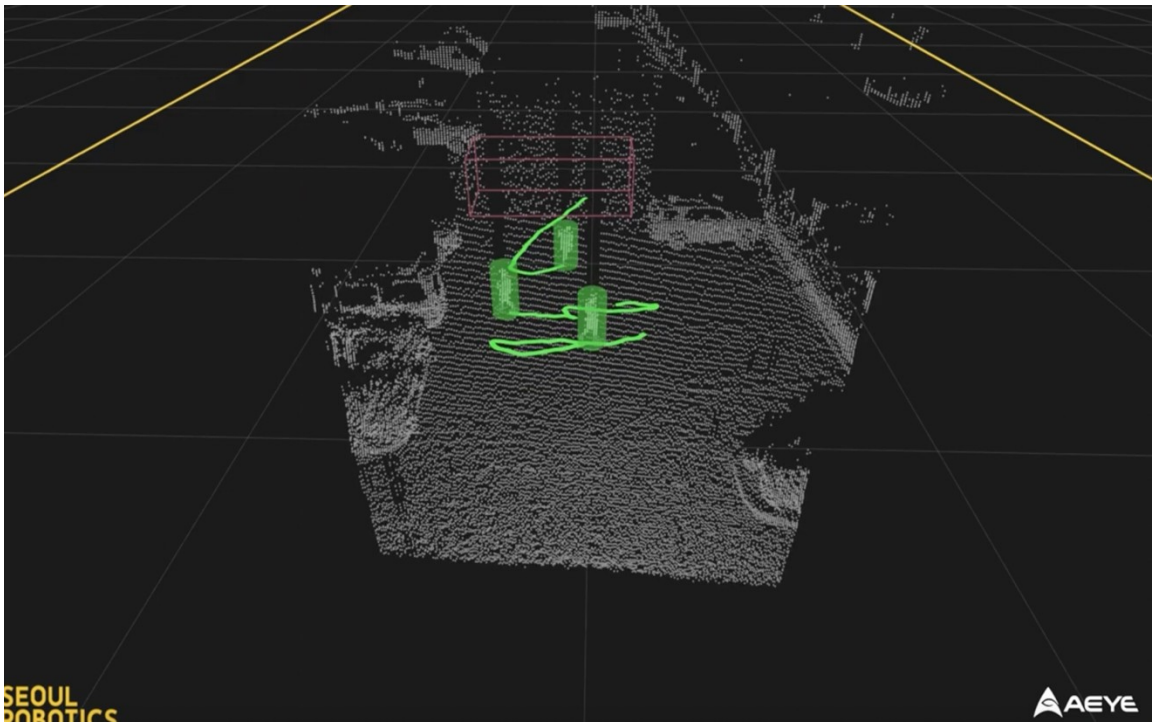


Figure 105 Screenshot taken from AEye YouTube channel https://www.youtube.com/watch?v=tZxsV-lPndU last accessed 14/03/2024.

However, the video highlights the difficulty of identifying these stylized human figures solely based on their visual representation, emphasizing the importance of verbal presentation to clarify their identity. The discrepancy between visual recognition and human perception raises questions about the system's effectiveness in accurately identifying and tracking pedestrians.

This kind of visualization is also present in Ouster’s videos, indicating how the production of Lidar for smart applications is migrating towards different primary uses

(see Figure 106). This theme will be explored in more detail in the last empirical chapter of this thesis.



Figure 106 Screenshot taken from Ouster YouTube video https://www.youtube.com/watch?v=638smEmj3mg last accessed 14/03/2024.

6.10 Narrative Elements

Another video highlights Velodyne's Lidar sensor designed for robotics applications. It follows a similar visual style to those already seen but emphasizes how Lidar acts as the "eyes" of robotics, while proprietary software serves as the "brain" to interpret point clouds (see Figure 107).

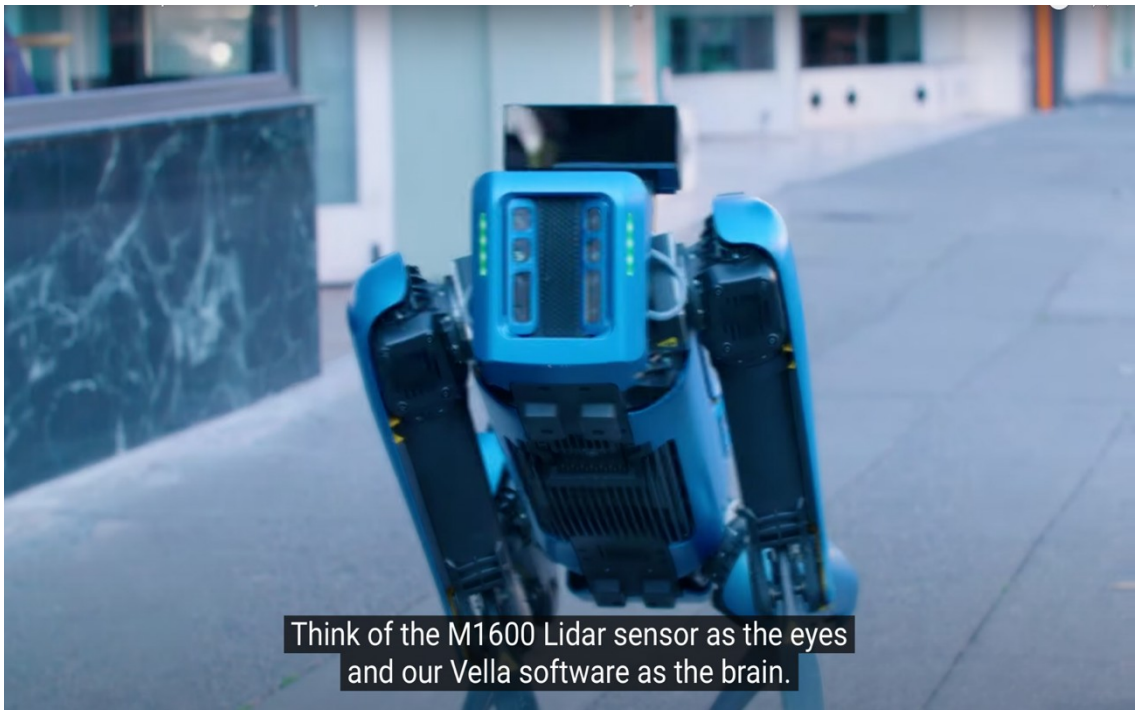


Figure 107 Screenshot taken from Velodyne YouTube video https://www.youtube.com/watch?v=jo4Iza4b0LI last accessed 27/07/2023.

Overall, Velodyne's marketing approach has evolved to showcase the real-world applications and partnerships enabled by its Lidar technology, with a visual style that combines cinematic elements with Lidar point cloud representations to convey the capabilities and potential of their systems. Such storytelling is sustained by the deployment of biological metaphors to highlight the functioning of the hardware and software stack, a linguistic use that's highly debated[28].

Luminar's approach to video production differs significantly from the aesthetic of their website. While the website emphasizes a sleek and minimalist design, the videos produced by Luminar often have strong cinematic features with curated cinematography and well-structured narratives, as already highlighted. As mentioned above, Luminar is

[28] Against the proliferation of biological metaphors in information, see Porcar (2019), a biologist explaining in detail how the processes described are in no way similar. Hayles (2004) sheds light upon how these metaphors found traction in pop culture after the Macy's conference (1960), in which cybernetic researchers established the parallel in order to gain more funding from the government.

one of the most proficient companies in the niche, given the high degree of engagement with consumers and investors. Luminar combines themes of safety with the value of entertainment and spectacle. For example, in 2021, the engineering team was part of an Indy race in which autonomous cars were competing against teams from different universities. A series of videos was produced as a result of this show. In one of these, after the company CEO directly connects the current experience to those of the DARPA challenges, the engineering team is shown while kissing the ground (see Figure 108 and 109).



Figure 108 Screenshot taken from Luminar Youtube video https://www.youtube.com/watch?v=CGmVZfynTcI Last accessed 14/03/2024.



Figure 109 Screenshot taken from Luminar YouTube video available at https://www.youtube.com/watch?v=CGmVZfynTcI Last accessed 14/03/2024.

6.11 Conclusion

This chapter embarks on an exploration of the intricate interplay between epistemic tools and their cognitive effects through visuality. The analysis traverses the divergent perspectives of two notable media scholars, Beer (2018) and Crary (1992), to unravel the ways in which normative practices are inscribed within certain technological artifacts. By weaving together these distinct viewpoints, the chapter aspires to offer an understanding of Lidar imaging, transcending the confines of commercial rhetoric, as it has been analyzed in the previous chapter.

To navigate this complex terrain, a pivotal point of departure is the Aspen Movie Map, a groundbreaking creation that often escapes notice as the precursor to contemporary technologies such as Google Street View. This creation amalgamates maps, animations,

film sequences, and auditory commentaries. It is enriched with a user interface featuring a touch screen and a joystick for navigation. The Aspen Movie Map stands as more than a mere historical artifact; it is deeply enmeshed in the genealogy of engineering, computer graphics, and the evolution of Geographic Information Systems (GIS).

While Wilson's recognition of geographical engagement with moving images within the past five decades is indispensable (2017), the roots of animated cartography can be traced back further in time. It bears a direct lineage, owing to shared efforts, techniques, and compositional tools with the realm of animation itself. One particularly compelling aspect of animation, the management of the line, as elucidated by Cubitt (2014), mirrors Wilson's exploration of the graphic elements in animated maps. These elements, beyond being visual constructs, serve as metaphors for materially actualizing geographical processes.

Subsequently, I turn our attention to Lidar videos. In doing so, I desire to bridge the theoretical underpinnings of diverse disciplines with the analysis of actual outputs of technological tools. This approach enriches the comprehension of Lidar imaging's significance beyond the limits of its own self-sustaining discourse.

This chapter strives to provide a nuanced examination that melds the insights from scholars like Beer and Crary, with elements pertaining to the history of cartography and animation. It proposes the Aspen Movie Map as a predecessor of Lidar sensing, as an epistemic tool, intertwining the histories of engineering, graphics, and GIS. Moreover, it underscores the symbiotic relationship between animated cartography and animation, drawing attention to their shared conceptual and formal underpinnings. Ultimately, by elucidating the nature of Lidar imaging through the prism of film theory, this analysis seeks to contribute to a deeper scholarly understanding of its implications.

The preceding analysis has illuminated the dynamics of human and machine points of view, within the realm of Lidar imaging, through the prism of camera framing. These dynamics are often imbued with shades of magical thinking and anthropomorphism. Notably, within the context of data visualization, it becomes evident that objects themselves hold little intrinsic significance in Lidar imaging. The presence or absence of humans seems almost ancillary in the process of constructing a representation of surfaces illuminated by technically drugged photons. The acts of segmentation through software and the subsequent curation of three-dimensional models of the environment, as perceived by machines, obscure the invisible interactions occurring at the subatomic level. What is presented to humans are curated depictions of hieratic surfaces, bereft of the underlying complexity (Human and Cilliers, 2013; Morin, 1992; 1999).

However, while emphasizing the capabilities of Lidar sensing, the montage also underscores how the sensor apprehends presence within an environment in ways that can transcend conventional Euclidean geometry and the fixed perspective of the human observer, at least as it has been historically determined up until this point. Lidar remains enigmatic precisely because it emerges from technoscientific thought, primarily designed to facilitate navigation within environments. In doing so, it constructs a digital realm that does not inherently cater to human exploration, as is the case with movies, games, art, or animated maps. This surplus in perception and sense-making emerges distinctly here, where I seek to dissect Lidar imaging and its corporate presentations. However, through its presentation in advertising and its translation for human comprehension, the collection of data, mimicking gridded patterns, as well as the organization of said data upon a grid, erodes the potentialities of algorithmic space sensing.

The challenge inherent in digital mapping and moving maps revolves around surfaces – animating surfaces, imbuing them with the luminosity of time, and traversing thresholds, while remaining within normatively established boundaries. In the confines of coordinates. Wilson, too, grapples with the intricacies of representing surfaces, particularly during the nascent stages of digital exploration within computer graphics. He alludes to examples such as ASCII art (2017:57-67), a technique for visualizing objects on screens using numerical and symbolic characters, to indicate a line of flight in the evolution of digital systems.

In Lidar sensing, it is the surface of objects that is illuminated by photons, and through calculations involving time, data is collected and organized into points that configure novel spatial dimensions upon a flat surface that mimics three-dimensionality. These spatial dimensions, when visualized on a screen, mimic the surface of a map, but encompass something that transcends it. The screen serves as an interface bridging two distinct spatial logics – the logic of the sphere and that of the table, as expounded by Farinelli (2009:160-165). The logic of the sphere is what sustains the diffusion of the Internet as an epistemic tool, as a hermeneutic of things: "a model based on the multiplicity of natural progressions, the existence of non-parallel series but intersecting among them"[29] (2009:161). The map is, instead, the "matrix of order" (2009:129), the device that can translate the world into tables, that can then be mobilized (2009:138) according to a standard for economics and politics. These two logics are intertwined, although irreducible from one to the other. According to Farinelli, the logic of the sphere is the form of self-conscience of the Table, of the map (2009:163). I argue that the screen that presents two different conceptualizations of time is the locus of this conscience, in the language of Farinelli, or what could be called transduction (Dodge and Kitchin, 2011). However, I argue, contra Farinelli, this doesn't speak about the crisis of cartographic

[29] My translation.

reason. The accomplished, screened transduction seems to herald an intensification of cartographic reason. These complex dialectics, among vision, perception, and space/time, represent the fascinating juncture where Lidar technology operates, and, in the next chapter, this nexus will be analyzed from a material perspective.

Chapter Seven

7.1 Introduction

All the companies comprising the larger sample reviewed in the fourth chapter exhibit a tendency to avoid precisely describing the inner workings that function within their sensors for data capture and software elaboration. Lidar imaging is thus occupying screen space mainly to contribute to an overall futuristic *aura* that the companies reclaim for themselves. Delving deeper into the commercial discourse surrounding these geo-visualities, in the fifth chapter, a series of categories have been shown to compose, in various combinations, how companies try to establish themselves in a determined niche, while underscoring their own peculiarities. Later on, the preferred visual strategy on proprietary sites heralded by Lidar videos, showing how differently colored dots animate the backdrop of the video, painting phantasmatic cityscapes or, alternatively, proposing a three-dimensional rendition of the sensing car and the surrounding environment, has been analyzed and inserted within a cartographic tradition that deals with animation, in the previous chapter. Usually, these two different possibilities in the visual efflorescence of the power of the sensing machine are present, as one does not exclude the other; they work in tandem to herald the cyber prowess of this digital mapping solution.

However, through different aesthetic choices, the discourse across the spectrum of the different companies working with Lidar for mapping purposes is rather homogeneous among them, disseminated through all those physical and digital outlets that they have elected to spread their message. Indeed, among informative sites, blogs, conferences, fairs and lessons, the discourse is always calibrated along the lines of amplifying the importance of Lidar in the city of the future, as the main technological champion capable of bringing forth a future that can be universally spread across the globe, a future of real-

time data capture, automated intelligence through the omnipresent power of mapping. Critically, all these promises are hinged upon an idea of safety, that can be reached and assured through algorithmic means. Safety, in the context of smart infrastructure building, of which mobility, here portended by the development of the driverless car through the power of Lidar, represents just one instance. Safety is also developed as the capacity to find patterns in the chaos of the crowd, to protect critical sites and avoid dangerous behaviors, as I will contend in chapter Eight.

The homogeneity of the discourse around Lidar represents an obstacle in the attempt to understand how Lidar mapping can be located within the larger history of cartographic efforts, as well as to reach a clearer picture of what kind of power and knowledge patterns it carries inscribed within the materials and processes that enable the sensor to create those specific renders of the world, in a mixture of spatial and visual features.

To approach Lidar mapping as a critical locus, I turned towards film theory, following a cue from geographers involved in doing and critiquing GIS (Pickles, 2003; Wilson, 2017), in the attempt to unearth theoretical and empirical evidence capable of shedding light on Lidar, that can go beyond mainstream discourse. This interdisciplinary approach (Cubitt, 2015; Wilson, 2017) was justified by the media in which Lidar is quite often presented to a wider public, either layman or specialist. In the previous chapter, videos showcasing streams of data were apprehended to specifically describe how space and time are meshed together in the moving image. For its very nature, the moving image tends to be immersive, and, thus, confusing. Considering the history of animation provided the tools to dispel confusion. Nonetheless, finding cues within media and film theory to achieve a better understanding of Lidar is also connected to the technoscientific evolution

of the sensor, which is materially tied both to cinema and defense research, as I'm going to show in this chapter.

Therefore, in this chapter, I'm going to explore the hybrid kinships of Lidar, and I will do so by reviewing, in the first place, the history of laser development, as it is connected to military research and also to cinematic projection techniques. A concept of digital materiality will emerge from this confrontation, a concept that will guide the analysis of the specific technical architectures of the eight companies already taken into account in the previous two chapters. The exploration of the digital materiality of hardware also needs a reflection on software, therefore, technical details about the physics and mechanics of the sensor will be repeated here, before delving into critical analysis. Moreover, given the epistemology of secrecy (Galison, 2004; de Ridder, 2013) around the development of Lidar for the Autonomy of Things, already described, I will find and discuss archaeological predecessors to the algorithms that might be deployed nowadays. Again, the uncertainty flagged in the methodological chapter, needs to be considered. In the conclusion, I will deepen the understanding of the problem of the interface between the logic of the table and the logic of the sphere, which emerged in the corpus and conclusion of the previous chapter.

7.2 Lidar advancements

As it will emerge in this section, Lidar is a remote sensing instrument that materialized through a series of contingencies and accidents, so it shouldn't come as a surprise that consensus is lacking even when it comes to the appropriate capitalization of the acronym. It's only in the last two decades that Lidar has risen as a pivotal digital technology, especially in the GIS community and in the engineering one, where it has found different

kinds of applications. In fact, most of the webpages from companies producing or deploying Lidar sensors present some kind of historical categorization that differentiates between airborne and terrestrial Lidar, then proceed to enlist the various niches in which this laser technology can prove to be helpful. These range from research purposes, which can have a governmental or academic reference – such as the study of the atmosphere or the surveying of coastal and forestry areas – to the selection of preferred areas for building infrastructure, mainly in the production of automated or semi-automated machines useful in the industrial sector or in public and private transportation.

Given the recent focus on Lidar as one of the central pieces of advancement that could bring about a new stage in automating vehicles, it can appear as a new emerging technology, ready to bring about mobility and a financial revolution. This is the refrain provided by the ensemble of manufacturers and Lidar enthusiasts. Nonetheless, while in the last year, these two different strands of enthusiasm have been curbed down by the reality of economic recession and the lack of a sustainable financial schema to support the numerous start-ups delving into this technology, the nebulousness around Lidar, how it works on a material level and what it can "see," has not been dissipated. In fact, it could be argued that the websites that publicize Lidar on the web, with their surface-level explanations, always accompanied by succinct infographics and flashy neon-colored images, contribute to the opacity of the system as a whole.

The first conceptualization for Lidar was born out of the mind of the Irish physicist Edward Hutchinson Synge (Donegan, 2012). He is known today for having produced in 1928 the first theoretically accurate description of the near-field scanning optical microscope, a technique used to visualize nanostructures through laser light (Synge, 1928). In the same year, he explained his idea in a letter to Einstein, whose theory about

stimulated emission constitutes the basis for later laser development, who replied to him that technically the idea was impossible to develop and demonstrate at the time, but still deserved to be published (Novotny, 2011). The microscope was realized only between 1982 and 1984 (Novotny, 2007). Nonetheless, Synge kept on working for the rest of his life on his research on microscopy and telescopy, and in 1932 proposed a new technique of remote sensing using searchlights (Donegan, 2007:30). His idea started being experimentally tested in 1935 and 1939 by the Carnegie Institution in the USA (Tuve et al. 1935), using searchlights to study ozone distribution in the atmosphere. The interest in this technology underwent a radical shift when, in 1940, the British Tizard Mission shared with the American Government the invention of the cavity magnetron, a device used for the production of microwaves in radar (Van Keuren, 1997). In the same year, the MIT Radiation Laboratory was founded in order to produce the essential technology needed to win the Second World War (Seidel, 1983). Only during the 50s did the interest in microwaves and stimulated light find new impetus, with the development of the optical maser[30], confirming Einstein's theory (Townes, 2002). In the beginning of the 60s, Hughes Laboratories produced the first "laser radar," which found applications in subsequent years in atmospheric and bathometric studies, NASA missions, and other military purposes (Smith, 1984). Laser-guided bombs were deployed in 1972 in the Vietnam War, and further research in cruise-missile guidance was carried out by the Air Force Research Laboratory until the system switched to GPS (Barkan, 1972). During the 80s and 90s, research on Lidar deployment remained highly tied to defense and territorial study. In 1998, Cyra Technologies produced the first commercial 3D scanner, along with

[30] A maser is a device that produces coherent electromagnetic waves, specifically microwaves, through amplification by stimulated emission. The term "maser" stands for microwave amplification by stimulated emission of radiation. The first maser was built in 1953 by Charles H. Townes, James P. Gordon, and Herbert J. Zeiger at Columbia University (Gordon et al., 1955). The laser, on the other hand, works on the same principle as the maser but produces higher frequency coherent radiation at visible wavelengths. The laser was inspired by the maser and was invented in 1960 by Theodore Maiman. In 1957, Charles Townes, the inventor of the maser and laser, discussed with Gordon Gould the idea of building an optical maser that works with light instead of microwaves. Gould noted this idea in his notebook and had it notarized. However, the first person to actually build a working laser was Theodore Maiman in 1960, who patented the pink ruby laser (Bertolotti, 2004).

its proprietary point-cloud software (Tucker, 2002), while in 2002, a professor at Carnegie developed the first SLAM software for scanning robots, to be deployed in mines (Nuchter et al., 2004; Thrun and Montemerlo, 2006; Thrun and Liu, 2005).

In 2004, the first DARPA Grand Challenge, a race for automated vehicles organized by the USA Department of Defense to stimulate engineering research in the field of automated transportation, was organized in the Mojave Desert, with no winners of the prize (Hooper, 2004). Nonetheless, the race sparked debate over the possibility of using Lidar with the aim of winning the race. The following year, 5 vehicles, out of 23 participating, managed to finish the race, with the first prize collected by the Stanford University team (Thrun et al., 2006). Although David Hall's Toyota Tundra was not successful, Velodyne's HDL-64 is based on its spinning Lidar (Young and Schwartz, 2010) (see Figure 110). The same sensor would be on the winning Tartan Racing Team guided by Carnegie Mellon Field Robotics Center professor Red Whittaker in the 2007 DARPA Grand Challenge, which took place in an air force base in California, with an urban setting decorated with realistic obstacles and signs, to be completed within six hours (Belfiore, 2007).



Figure 110 Screenshot from technical booklet available at https://pdf.aeroexpo.online/pdf/velodyne/hdl-64e-s3/176220-7836.html

In 2011, Google silently bought 510 System, a start-up founded by one of the participants in the second DARPA challenge, that built itself a great reputation in

automatic mobile mapping (and also worked in tandem with director Frost to use raw Lidar data in the Radiohead music video "House of Cards") and constituted the "secret" mapping core of the Google Street View endeavor, with the building of a Lidar-based self-driving car based on a Toyota Prius called "Pribot," since 2008 (Harris, 2014).

From this synthetic first exploration into the history and evolution of Lidar technology, it is apparent that laser light sprang out at the crossroads of defense, research, mapping, industrial secrecy, and the manipulation of light. To understand Lidar sensing, it is necessary to understand the emitting source of photons, providing the digital translation of volumes into digital point-cloud data.

A searchlight is a device that combines an incredibly bright source—typically a carbon arc lamp—with a mirrored parabolic reflector to aim a strong beam of light in roughly parallel rays towards a target. Its military use has been in place since the Siege of Paris in 1870, during the Franco-Russian War, in what can be described as one of the first attempts to militarize light (Cubitt, 2015). Since then, the usefulness of searchlights has become evident on the battlefield for illuminating it, confusing the enemy, and aiding in complex maneuvers. However, searchlights, as an evolution of the lighthouse—with which they share a source of light amplified by a mechanism of glass lenses and mirrors but with completely different purposes—have also been deployed in architectural spectacles to entertain the masses, as seen in the work of Albert Speer for the Nuremberg rallies in Nazi Germany. Searchlights were also used for grand spectacles in stadiums and large mass gatherings and have been replaced in such intangible architectural displays by lasers. Nonetheless, searchlights still maintain an unusual connection with another mass spectacle technology: "Cinema projection provided the testbed for these new forms of organized light" (Cubitt, 2015, p. 45).

The projection system is, in fact, composed of a very bright lamp—a carbon arc light until the 60s, and then a xenon one—along with a lining to prevent the scattering of light, two convex lenses to focus it toward the aperture, which then projects it onto a far distant screen. The projection system has now evolved into a completely digitized system, in which light is directed towards a chip housing a dense series of digitally controlled micromirrors.

In a similar process of digitalization, light from the searchlight evolved into laser technology.

A laser, which stands for "Light Amplification by Stimulated Emission of Radiation," is an apparatus that produces light using an optical amplification technique based on the stimulated emission of electromagnetic radiation. In other terms:

> […] laser, relies on controlling the random production of light typical of the sun, flames and incandescent lamps. Like flame and incandescent lights, lasers use the photons released by the movement of electrons between states of excitement. Unlike flame or incandescent bulbs, lasers use a form of amplification of light by passing a beam repeatedly between mirrors through a 'gain medium' (usually crystal, glass, metal or inert gases or semiconductors, but also liquids in so-called dye-lasers). In the gain medium the photons, released when electrons from atoms of the same composition and state of excitement release their energy, scatter as usual, but the paired mirrors encourage those photons travelling along their axis to continue bouncing to and fro, as they do so spurring other electrons to release their energy in the same wavelength as the one triggering the release. Thus the laser produces increasing numbers of photons of identical wavelengths tuned to one another ('in phase'). Once this reaches a critical quantity, photons travelling along the axis pass through the half-silvered mirror at one

> end in the form of an intensely focused beam whose wavelength is a function of the distance between the two 'resonating' mirrors. (Cubitt, 2015, p. 53).

The burst of white light produced by specific light pumps passes through the gain medium, whose purpose is to polarize it, not so much to control color, but especially to control the phase and wavelength. This way, incandescent light is transformed into coherent light, whose waves can be encoded and decoded to carry out information. In a first period, this ability to transport data through signaling was put to the test with airborne transmission, but due to atmospheric conditions, the signal would dissipate. It was only through successful experiments in the USA, UK, Japan, and Russia, lasting through the 60s and 70s, that scientists were able to exploit the micro transmitting qualities of lasers, making them flow through very fine flexible glass pipes. The principle at the basis of fiber optics is total internal reflection. The basic idea is that two glass tubes with different refractive indexes fused together in a filament rod exhibit the capacity to better guide and amplify coherent light waves carrying information. It's important to note how a complex grammar of glasses and lenses and accidental experimental convergences gave birth to the biggest revolution in telecommunications. Where fiber optics, telecommunications, and robotics met, Lidar was born.

Lidar, an acronym standing for Light Detection and Ranging, is an optical device used for sensing distances. As already seen, a short burst of laser light is shot towards the target, and the distance is then calculated by recording the interval between the outgoing pulse and the detection of the backscattered light. The calculation operates on a simple formula determined by the known speed of light: dividing by two the time taken by a photon to hit the surface of the target and then get back to the receiver, it's possible to calculate the range between the scanner and the object. This form of direct measurement of time of

flight requires an incredibly precise way of measuring time in the order of picoseconds – a thousandth of a nanosecond or a thousandth of a billionth of a second.

Another preferred method to measure distance consists in comparing the phase of the square waves of light in both directions: this is the indirect method to measure time of flight. Moreover, Lidar devices are not all the same; they exhibit different architectures, materials employed, and different physical principles to respond to different tasks.

A first distinction to be made is between airborne and terrestrial Lidar. Lidar to be deployed in the atmosphere and beyond has different range and accuracy needs than terrestrial Lidar. And then again, terrestrial Lidar can be either static or mobile. Mobile Lidar devices are the ones deployed in robotics to answer to different kinds of needs concerning action planning and control of the environment. They can be used in every situation in which a machine needs an accurate representation of space to control mobility, ranging from automated vacuums to different levels of automated vehicles.

As already shown by the brief history outlined above, Lidar is essentially a projecting technology: a laser beam is shot out by the device towards a surface, and such a beam of light can be manipulated in many different ways to generate a scanning effect. Understanding the implications of projection represents the most important step in positioning Lidar sensing in a larger cartographic tradition. However, it's also important to further consider how the current and most common Lidar sensors for the automotive sector came to be.

Historically, the first Lidar device to achieve success in the DARPA Grand Challenge was the Velodyne HDL-64E. The patent for this device is in the name of David Hall, one

of the company's founders. Although officially retired from production in May 2021, it represented the state-of-the-art solution for Lidar visualization for several years. This sensor found applications in both the development of self-driving cars and sea navigation. The Velodyne HDL-64E is classified as a spinning or spindle-type Lidar, meaning that it employs a mechanical technique to produce the desired scanning effect.



Figure 111 First of a series of screenshot taken from the YouTube video https://www.youtube.com/watch?v=bUVtT7Gp2Z4 Last accessed 28/09/2023. The video is a historical one from the company Velodyne, an engineer dissects and shows the inner working of the HDL-64E sensor.



Figure 112 Second of a series of screenshot taken from the YouTube video https://www.youtube.com/watch?v=bUVtT7Gp2Z4 Last accessed 28/09/2023.

As the name implies, this device features 64 channels. The top section of the bucket-shaped rotating component houses 32 lasers paired with 32 receivers, and this architecture is duplicated below. This arrangement is responsible for the scanning pattern observed in many data visualizations produced by this specific type of Lidar. Typically, these visualizations show a central blank circular spot, indicating the scanner's location along with its blind spots, surrounded by differently colored rings representing the collected data across the available range.

The 64 channels, as described, cover a total field of view of 29° vertically, while rotation ensures full coverage horizontally. Users can select the rotation rate, which determines the density of the point cloud, reaching up to 2,200,000 points per second. The laser emits

shots at a wavelength of 903 nm, placing it in the near-infrared part of the electromagnetic spectrum. The backscattered light is received by an avalanche photodetector, responsible for converting the wavelength into an electronic current for subsequent data processing.

In traditional Lidar systems, various mechanisms are employed to rotate the beams and capture three-dimensional data, such as a single spinning mirror, multiple mirrors, or a polygonal mirror. Velodyne introduced innovation by mounting the entire set of lasers and receivers on a spinning mount. This design also facilitated the encoding of the rotation pattern for more accurate data extraction. However, it did not completely eliminate the challenges of moving parts in a tool that needs to be mounted on mobile machines operating in unpredictable conditions. Additionally, these devices were expensive, making scalability a challenge. Consequently, other startups began exploring architectures aimed at eliminating moving parts, reducing costs, while preserving the need for dense point clouds.

The solution to this challenge has been found in the development of what is known as "solid-state Lidar", or “Lidar-on-chip”, which seeks to integrate all sensor components into a single chip. Solid-state Lidar typically features a design that is easier to integrate into vehicles, promising cost reduction, scalability, and increased resilience to environmental conditions. However, it often does not offer a 360° field of view, and beams need to be steered towards targets using micro-electromechanical mirrors (MEMs) or optical phased arrays (OPAs). The latter method is also compatible with laser systems based on a coherent laser approach. This approach differs from pulsed Lidar, which measures the time of flight of light beams. Coherent Lidar, by measuring the frequency of outgoing and incoming beams and calculating the Doppler-shift effect, not only determines position and direction but also the velocity of the target.

Another less-discussed solution, among Lidar producers, involves digital beam steering through birefringent crystal liquid cells. The principle of "double refraction," another term for birefringence, is rooted in the Snell-Descartes law of refraction, dating back to the mid-seventeenth century (Dijksterhuis, 2004; Scott, 2016). In 1678, Dutch mathematician Huygens, while analyzing the trigonometric properties of Snell's refraction through an Icelandic spar, formulated the principle of birefringence, a key element in the digital beam steering of Lidar (Kristjánsson, 2012). To alter the direction of Lidar pulses, a stack of alternating liquid crystal cells is deployed at various angles, designed for a specific wavelength. These liquid crystal cells consist of transparent cells containing a thin layer of liquid crystal, along with special coatings applied to the rear and front substrates. These coatings create the necessary boundary conditions and apply alternating square voltage fields to modify the liquid cell material, allowing them to function as polarizing filters (Lin et al., 2022).

Another time-of-flight-based approach is represented by Flash Lidar. In contrast to other types, where each beam corresponds to a pixel in a raster scan, Flash Lidar employs a single beam to capture an entire scene, much like a conventional camera, but with a focus on distance.

This schematization is not complete and is primarily provisional; it's almost impossible to calculate the number of technical affordances resulting from the combination of various elements, such as laser emitters, receivers, transistors, all made of different materials. Additionally, one must consider every other component alongside the pairing of different layers of algorithmic processing and software manipulation. The field becomes particularly challenging to summarize, especially when factoring in that cutting-edge research is progressing towards nanophotonics (Li et al., 2022).

7.3 How engineering is epistemically similar to map-making.

In the context of the Literature Review, the Post-phenomenology of technology emerges as a profound exploration of the relationship that exists between humans, technology, and the world. This exploration becomes particularly significant within the framework of digital technologies and automation. At its core lies the concept of hermeneutics, an intellectual discipline of interpretation that serves as a critical tool for unraveling the complexities of this relationship. Hermeneutics assumes a paramount role in enabling our comprehension of how humans engage with technology and, in turn, how interfaces mold our perception of the world.

Within this discourse, Don Ihde's notion of "technoscience" emerges, underscoring the connection that binds scientific practice to the material tools that facilitate it. This perspective accentuates that technology, including digital advancements, carries within itself a distinct worldview and selectivity. These attributes influence the way humans perceive and interpret their surroundings.

Digital technologies wield the power to mediate the world and actively shape the worldviews of their users through the lens of digital materiality. To elucidate this phenomenon, a fundamental distinction is drawn between the "substrate" and the "trace." This differentiation serves to underscore the critical role that materiality plays in the impact of epistemic tools.

The hermeneutic relationship seems to be currently shifting, a transformation precipitated by the pervasive influence of digital technologies. Humans find themselves increasingly molded and influenced by the data extracted and meticulously processed by

advanced technologies. This paradigm shift prompts a reevaluation of the human role in the interplay between hardware and software.

The connections that bind humans, digital technologies, and their impact on perception and interpretation demand meticulous examination and emphasis within the scholarly discourse. This exploration is central to comprehending the implications of technology on the human experience, making it a focal point of this research.

In the context of this exploration, it becomes evident that companies' websites are organized around distinct brand aesthetics, as previously discussed in the preceding chapter. These aesthetics can be primarily categorized into two predominant visual themes, each conveying a distinct message and vision.

The first visual theme emanates a sense of minimalism, adopting a digital appearance characterized by a color palette predominantly comprised of black, white, and occasionally subdued tones. This visual organization reflects a futuristic vision of order, rooted in the simplification of life, a future to be ushered in by automation. It symbolizes a promise of a streamlined existence where mundane tasks are seamlessly handled by technology, affording individuals more time for self-enrichment. Safety and security underpin this aesthetic narrative.

Conversely, the second prevailing aesthetic veers towards darker tones interspersed with striking neon colors, hinting at a future where automation transforms daily life. In this envisioned future, humans are unburdened by tasks that induce stress and pose risks to lives. This aesthetic signifies a promise of liberation from the mundane, with technology facilitating a more secure and comfortable existence. Safety and security remain pivotal

themes. These are the ways in which the imaginary of Lidar imaging is articulated through images and videos presence on websites.

The discourse surrounding the development of driverless cars invariably revolves around the idea that these software-enhanced vehicles possess the potential to save lives during accidents. This potential stems from their unique capabilities, rooted in data extraction, precise planning, and vigilant control. These capabilities, unlike their human counterparts, are publicized as immune to limitations stemming from factors such as attention span, visual impairment, or behavioral issues.

When elaborating on how this ultimate goal of accident prevention is to be realized through driverless cars equipped with Lidar sensors, which are depicted as superior to human visual acuity in road management, the explanations appear deceptively simple. Explanations of sensor functionality, in tandem with other sensors and accompanying software, are often sustained by accessible visual aids such as diagrams or vector graphic illustrations. However, this simplicity is underpinned by a two-fold rationale. Firstly, the engineering intricacies underlying automation are staggeringly complex, encompassing hardware, layered code, and software, all necessary to interpret incoming data. Secondly, a shroud of industrial secrecy envelops the development of software solutions that tackle the many challenges posed by automating cars in inherently chaotic, unpredictable, and disorderly urban environments (Lorinc, 2022).

The depth of insight accessible during interviews with developers, even across multiple sessions and with the inclusion of screen sharing, often remains limited, failing to exceed the simplicity of explanations available to the broader public. For instance, in a conversation with a perception engineer from one of the leading autonomous driving

companies, which redirected its focus from fully autonomous robotaxis to last-mile automated delivery in response to the economic ramifications of the COVID-19 pandemic, inquiries regarding their work led to the sharing of a link to a Medium blog post titled "Perception: How Self-Driving Cars 'See' the World" (Dholakia, 2019). Medium, a platform that facilitates the sharing of provisional research and insights, boasts an active community of coders and programmers who contribute explanations and tutorials related to their work.

The blog post commences with a graphical representation of a car, serving as the focal point of an intricate network of triangles, each adorned with varying colors, symbolizing the diverse sensors adorning the vehicle. The author proceeds to elucidate the intricate workings of a "complex of visual sensors and machine learning" that empower the vehicle to "perceive" its surroundings and formulate decisions in pursuit of reaching a destination without endangering human lives. Metaphors borrowed from the realm of biology paint the vehicle's sensors as its eyes, with convolutional neural networks acting as its cognitive brain.

The blog post goes on to enumerate the array of sensors essential for the vehicle's functioning, highlighting their distinct advantages and limitations in data extraction from the surrounding environment. For instance, radar emerges as a cornerstone technology for automated cars due to its remarkable capacity to reach vast distances. Utilizing time-of-flight measurements, radar can ascertain the distance and velocity of objects in motion around the vehicle. However, radar's precision diminishes for objects in close proximity, a critical consideration for vehicle safety.

Cameras constitute another indispensable component of the vehicle's sensory apparatus, enabling the extraction of information from objects lacking depth, such as discerning the color of traffic lights or interpreting the instructions conveyed through traffic signs. Through the process of sensing fusion, the data derived from radar, which identifies an object's distance and speed, is cross-referenced and corroborated with visual data captured by the camera. This information is subjected to machine learning and computer vision algorithms within the car's software, enabling the system to fuse, analyze, and ultimately determine the identity and nature of each detected object.

The blog post further delves into the arrangement of sensors, eventually introducing Lidar as a pivotal component of the perception stack. Accompanied by a bird's-eye-view point-cloud representation of a road, the blog offers a simplified explanation of Lidar's functionality – calculating the time of flight of laser beams. Lidar is praised for its exceptional precision, even at significant distances, enabling it to generate a "depth map" or a "point cloud map." Due to its density, this point cloud map can discern the types of objects present in the environment. However, it's important to note that Lidar's effectiveness can be compromised in certain weather conditions, necessitating the need for complementary radar and GPS coordinates.

The blog concludes by painting a vivid picture of the transformative potential of driverless cars. It envisions a future where automation eliminates fatal accidents, liberating valuable time for leisure and other pursuits. However, it acknowledges that realizing this vision will require a monumental overhaul of urban infrastructure and a radical shift in the concept of individual property ownership, ultimately creating an environment where every vehicle can operate autonomously, within a fleet.

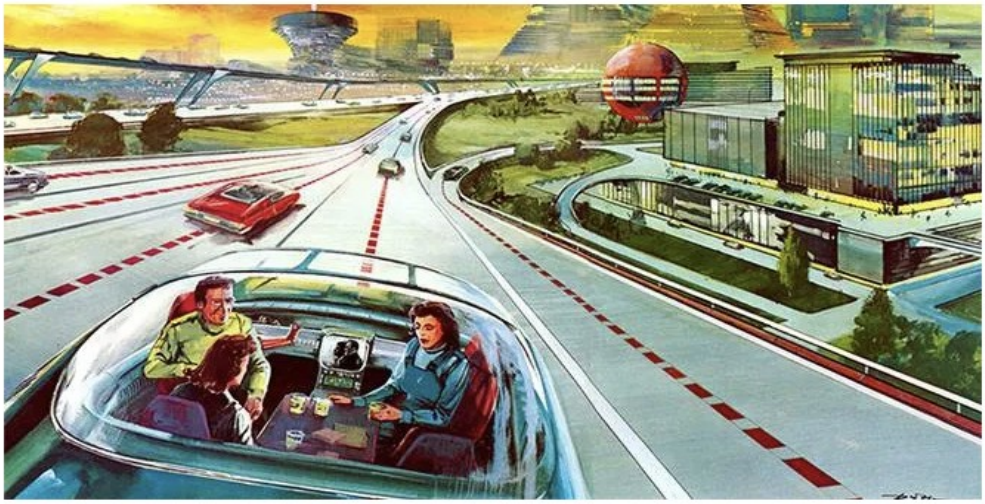


Figure 113 Screenshot taken from https://swarit.medium.com/perception-how-self-driving-cars-see-the-world-ae630636f4c . Last accessed 25/10/2023.

This simplified yet comprehensive explanation encapsulates the core elements of the discourse prevalent in panels, conferences, and educational settings. However, during my interviews, I encountered difficulties in delving beyond this thick but straightforward narrative. Inspired by Matthew Wilson's suggestion to explore the creative agency of programmers, I attempted to redirect my questions, moving away from abstract inquiries about the engineering work and instead focusing on extracting their narrative about their personal contribution to the work, but to no avail.

This shift appeared promising, especially considering the prominent role of 3D visualization software in architectural projects, which has led to fresh insights into the interaction between humans and machines, within a context heavily influenced by suggestions that polynomial functions might reveal new venues of creative freedom (Poulasgaard and Malafouris, 2020). However, my interviews revealed that perception engineers do not readily perceive their interactions with the software layers responsible

for processing incoming data as creative endeavors. Nevertheless, my analysis of the output video data in the previous chapter clearly illustrates a process of creative selection, at least in terms of choosing colors to represent different depths detected by Lidar. Moreover, this creativity extends to the extraction of 3D models from point clouds and the subsequent creation of streamlined explanations for dissemination on proprietary websites and outlets catering to both expert and general audiences.

Despite my persistence in probing these aspects, the responses I received often amounted to a simple: "It's cool." In this context, "coolness" encapsulates the awe-inspiring capabilities of the Lidar sensor, which can extract a worldview that is both astonishing and practically versatile. It also captures the "cool" aesthetics of the resulting images, portraying a world on the cusp of a cyber revolution, frequently aligning with utopian visions.

This overarching image is predicated on the remarkable achievement of transforming the chaotic urban landscape into an orderly, real-time, evolving representation of events. According to Mohl's elaboration, this grid-mapped *and* three-dimensional visualization allows for predictive decision-making, thanks to improved learning capacity (Mohl, 1981:196-199). Lorinc (2022:219) characterizes this as a "dream state," the latest evolution in urban planning practices aspiring to transform the cityscape into a "dreamscape" of order and prosperity, where accidents can be completely controlled to pave the way for a better quality of life.

The dream of attaining fully autonomous mobility, within the broader context of creating smart cities, aligns with this aspiration. It is conceptualized as a comprehensive urban planning strategy aimed at achieving a harmonious and accident-free urban

environment. However, compelling empirical evidence suggests that such utopian plans often yield unforeseen urban zoning effects. Lorinc (2022:236) contends that returning decision-making power to the collective wisdom of politicians, city planners, civil engineers, and domain experts is essential. This approach would foster tailored solutions to address specific urban challenges and ensure that the complex and dynamic nature of urban life is adequately accounted for.

While Lorinc envisions the development of fully automated cities, where smart mobility is just one facet, Siegel and Pappas (2021), two engineers from Michigan University, delve into the ethical dimensions of the challenges posed by driverless cars. They initiate their paper by acknowledging the promising evolution of sensing technologies and their applications in simulated environments, which hold the potential for a significant transformation in mobility and a substantial enhancement of safety in driving. It's important to note how they underscore the importance of uncertainty in designing algorithmic tools to be deployed in the urban environment.

The insistence on safety may reflect an extreme form of obsessive rationalization in response to the impossibility of fully mathematizing the unknown and predicting automated responses to events beyond probabilistic calculations.

7.4 Hardware Architectures

As seen above, the paper by Siegel and Pappas highlights the inherent complexity involved in encoding ethics in the software for the development of driverless cars. This complexity, as I will show in this section, is not reserved to software. It encompasses also various aspects, including the materials used in sensor construction, the sensor's

constituent elements and mechanics, the underlying physics governing sensor operation, data extraction methods, data storage and optimization, and the multiple layers of coded algorithms employed to process data and produce operational outputs. These outputs serve both human control and the decision-making core of the machine.

In the current economic climate, the analysis of proprietary software remains a challenging endeavor due to its unavailability for scrutiny. However, to explore deeper into the digital materiality of Lidar, I proceed to examine the hardware architectures deployed by the seven companies previously investigated. This information is not commonly readily accessible, as each company often touts its solution as the first or best in a highly competitive landscape focused on performance, vision, and intelligence in achieving scalable full automation.

As previously discussed, AEye's website maintains a clean and minimalist design characterized by a color scheme dominated by black, white, and subtle shades of blue and green. The main text emphasizes their vision for a safer future and is complemented by graphical representations of orderly roads traveled by cars, conical figures representing trees along the road, varying-sized parallelepipeds signifying buildings surrounding the path, green stick figures crossing the road, and a prominent concentric arc emanating from the traveling car. This arc symbolizes the perceptual activity that would otherwise remain invisible. The website introduces their sensor, capable of surpassing the limitations of radar and cameras, as "Software-Definable Lidar."

Clicking on the "learn more" button directs users to the "tech page." Here, the same vector graphic style seen on the homepage is maintained, while the sensor is described as a solid-state Lidar with a patented bistatic architecture. This architecture distinguishes

itself by having laser emitters and receivers for backscattered pulses occupy separate channels. The description further explains that the receiver is directed toward the area where the laser shot was sent, imbuing "intelligence" into the hardware through software. The page proceeds to list the sensor's main characteristics: solid-state construction, the option to integrate camera data with Lidar data, and upgradability. While this description succinctly highlights the company's strengths compared to other market proposals, it does not delve into the sensor's digital materiality (see Figure 114).

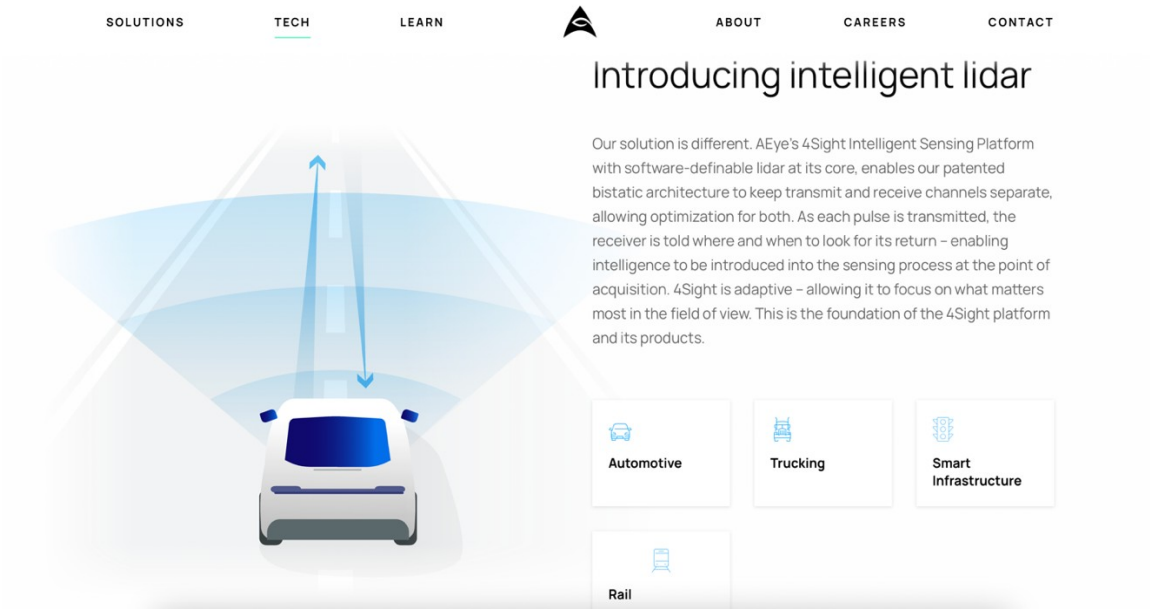


Figure 114 Screenshot taken from https://www.aeye.ai/4sight-lidar/ . Last accessed 28/09/2023.

To access more technical details, it's necessary to navigate to the "Resources" section of AEye's website, where the thirty-ninth entry seems promising for shedding light on AEye's sensor technology. Clicking on this page redirects to a white paper titled "Time of Flight vs. FMCW LiDAR: A Side-by-Side Comparison." This paper aims to address the ongoing debate among Lidar companies, especially those employing different Lidar technologies (see Figure 115).

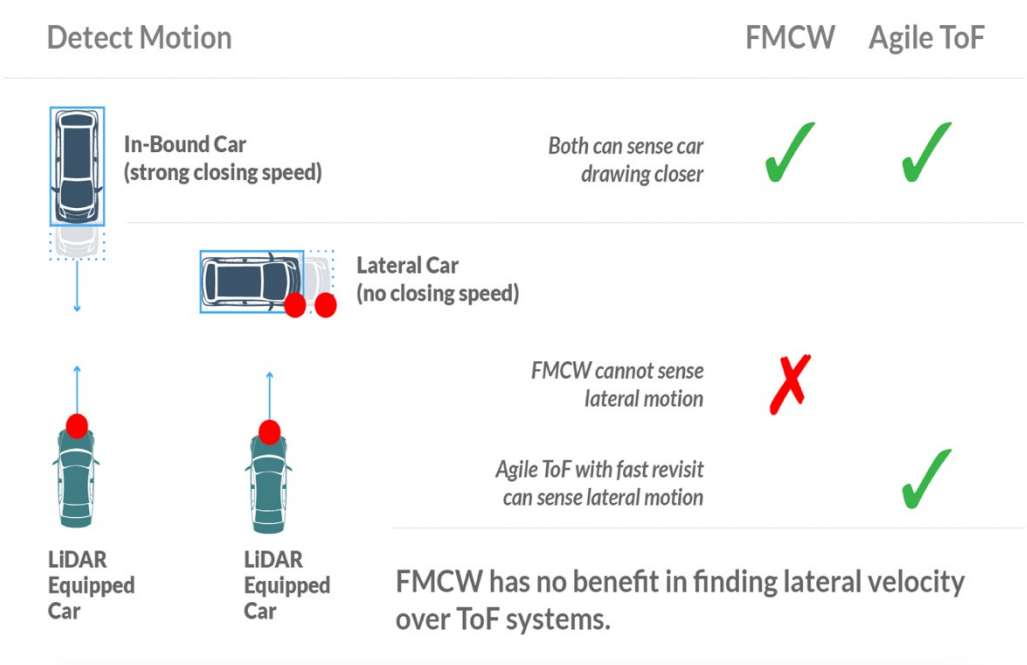


Figure 115 Screenshot taken from https://www.aeye.ai/resources/white-papers/time-of-flight-vs-fmcw-lidar-a-side-by-side-comparison/ Last accessed 28/09/2023.

The paper claims that FMCW Lidar is a groundbreaking technology, tracing its historical origins back to the 1960s and its resurgence with advancements in laser technology. AEye asserts that their sensor offers superior performance, emphasizing its higher laser shot density in both spatial (field of vision) and temporal (scanning speed) dimensions, enabling noise filtering and the detection of small objects at varying distances.

AEye challenges assertions that FMCW Lidar excels at detecting velocity efficiently. While FMCW sensors measure wavelength changes to determine radial velocity, they are constrained by dwell time. In contrast, Time of Flight (ToF) Lidar is not tied to dwell time and can extract statistically reliable data about the surrounding environment as a whole.

AEye's white paper also disputes claims that frequency-based Lidar is immune to interference. According to AEye's description, frequency-based Lidar is more susceptible

to interferences due to how the receiving antenna is designed and how frequency is continuously measured over time, leading to "clutter" or self-interference and ambiguous results caused by surface reflectivity.

Lastly, AEye challenges assertions that FMCW Lidar is poised to bring about industrial scalability, noting concerns related to the supply chain for low phase noise lasers, especially for automotive-grade reliability.

In summary, AEye's white paper offers insights into the technoscientific and financial debates within the perception design community of Lidar for the development of driverless cars. The primary division revolves around companies that advocate for Time of Flight (ToF) Lidar, measuring time of flight, and those promoting Frequency Modulated Continuous Wave (FMCW) Lidar, measuring frequency changes.
Reading through the bibliography of the white paper, it becomes clear that it has been written bearing in mind the biggest producer of Lidar-on-Chip: Aeva.

On the contrary, Aeva's approach to Lidar technology revolves around Frequency Modulated Continuous Wave (FMCW), which allows them to eliminate all fiber optics from the Lidar sensor. By integrating all components onto a single silicon chip, their system can detect velocity, depth, reflectivity, distance, and motion without the need for further calculations. This, together with the calculation of the Doppler effect, explains their emphasis on the concept of 4D mapping, seen in the previous chapter, where the velocity of moving objects is incorporated into their spatial data representation. This also accounts for the different colors observed in their point clouds: the environmental elements are represented in grayscale, while moving objects are color-coded based on their direction and velocity.

Aeva's solution essentially represents a complete digitalization of Lidar technology, divorcing it from any mechanical parts (see Figure 116 and 117).

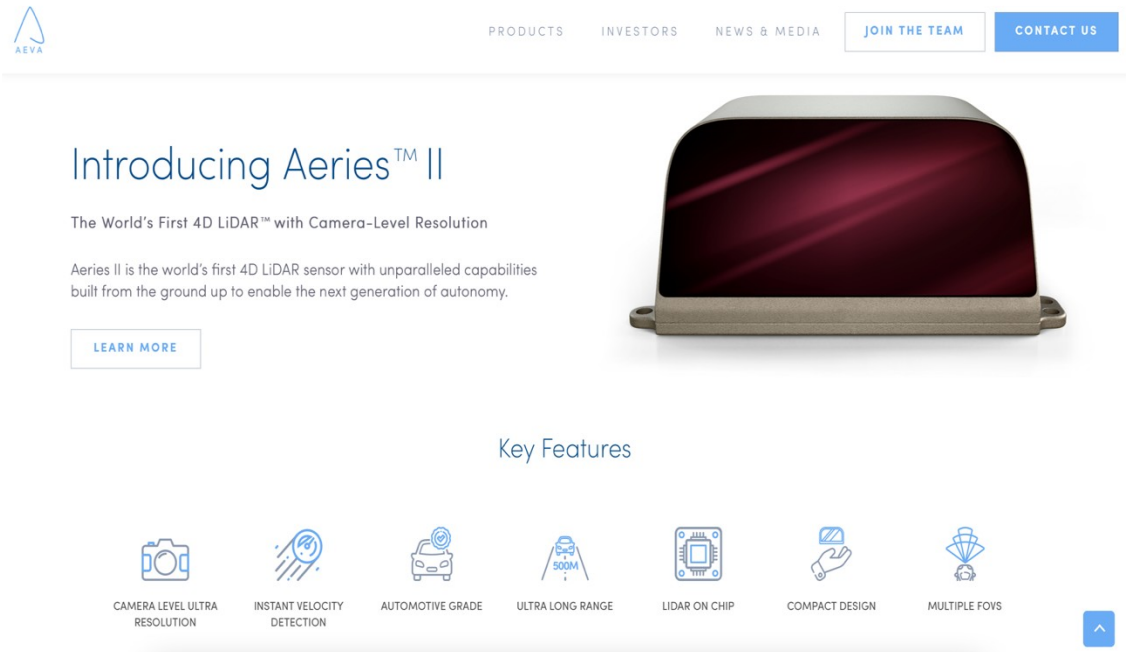


Figure 116 Screenshot taken from https://www.aeva.com/ Last accessed 29/09/2023.

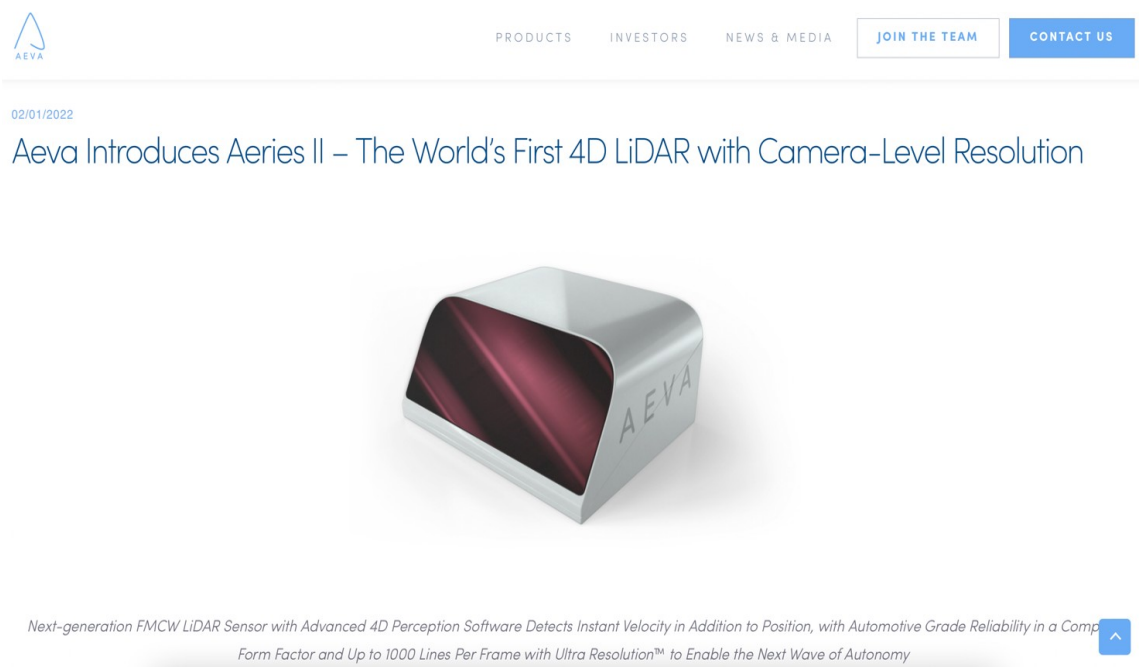


Figure 117 Screenshot taken from https://www.aeva.com/aeries-ii/ Last accessed 29/09/2023.

Clicking on the "learn more" buttons doesn't lead the internet user towards a technical data sheet. Proceeding with the site exploration on the page "News and Media", the thirty-sixth entry brings to the press release mainly concerned with the presentation of the sensor. This page, too, doesn't get into the benchmarks of the sensor, that I was unable to find. However, it describes Aeva's Aeries II in enthusiastic terms: it is an advanced 4D Lidar sensor utilizing Frequency Modulated Continuous Wave (FMCW) technology.

The elements of the sensor are all based on silicon photonics technology, a form of manufacture that requires high hatching precision. Aeva sensor boasts camera-level resolution, along with the ability to detect objects up to a distance of 500 meters, as we have seen effectively showcased by the company's visual strategy in previous chapters. One of its distinguishing advertised features is its resistance to interference from sunlight and other Lidar sensors, including Aeva's own sensors. This ensures consistent performance across a broad range of lighting conditions and when operating in proximity to other Lidar-equipped vehicles. Given the absence of mobile parts, Aries II is marketed as resistant to shocks, vibrations and temperature variations. As seen before, the mathesis

behind the detection of velocity with space makes it suitable for different applications in autonomous vehicles, robotics, and other scenarios requiring sensing capabilities.

In the same press release section, the merits of the sensor are effectively testified by the partnership established with Tier1 Automotive Suppliers for the development of ADAS, as well as a partnership with NASA, for the mapping of the Moon.

Nonetheless, I wasn't able to find any press releases or white papers trying to dispel AEye's objections towards the security and maturity of Lidar-on-Chip technology. However, many of the claims boasting the characteristics of the sensor can be seen as attempts to dispel those doubts, without directly confronting it. It still remains the fact that it was impossible to find a neutral description of the sensor, along with specific benchmarks.

The Lidar-on-chip approach is also adopted by Ouster, a company that recently acquired the well-established Velodyne. Ouster's product catalog currently includes both spinning Lidar solutions and Lidar-on-chip offerings, and this is currently represented by the visual organization of their homepage (see Figure 118). In the first place, the merge with Velodyne is presented, being here heralded by a series of shots presenting the work of the merged company with small robotics for last mile delivery and industrial applications. After the spinning sensors, which Velodyne still produces, Ouster presents their main product.

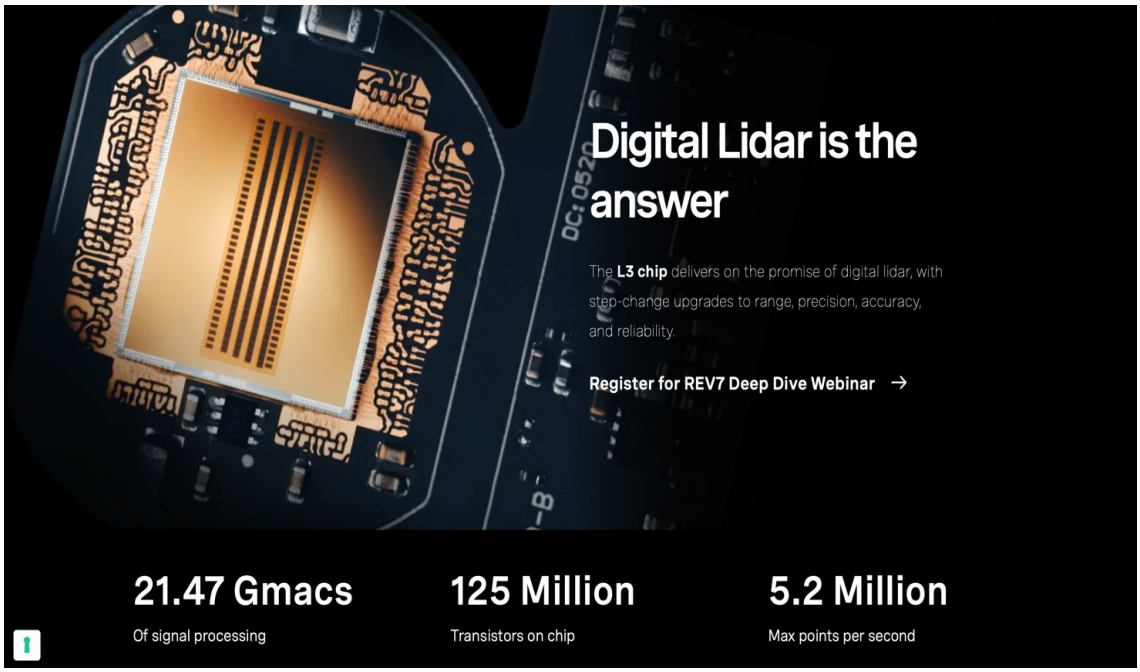


Figure 118 Screenshot taken from https://ouster.com/ Last accessed 20/09/2023.

In the presentation of the product, we can see once again how *the exhibition* of benchmarks is exploited to produce and sustain an image of cutting-edge technology, capable of delivering the future of perception and mobility. Just under the showcased benchmark, a button leads to a webinar that can be accessed only through an invitation. However, clicking on the bar on top, at the voice "products", leads to a page dedicated to the REV7 Sensor: "engineered for engineers". A cinematic presentation video, equipped with truly beautiful shots, edited upon a classical music as soundtrack, demonstrates the different applications of the sensor (see Figure 119).



Figure 119 Screenshot taken from the embedded video at https://ouster.com/ . This sequence wants to visualize the seamless projection of point cloud data points upon the peaceful shot of a canal. Last accessed 20/09/2023.

After the cinematic presentation, which presents a wide array of industrial and research applications, the CEO of the company presents the main characteristics of the sensor.

For instance, the design of the sensor, with all of its components on a single chip, is recounted in an incisive manner. Other features poetically described, with the inclusion of impressive benchmark numbers, are the density of pixels and the capability of the sensor to adapt to its surroundings through randomized beam steering. Additionally, the Ouster Lidar-on-chip sensor gets praised for its power, making it suitable for the growing demand for solutions in the field of robotics.

Considering the rest of the page, after the videos, this company relies very much on density of data, which gives their maps a cybernetic aesthetic quality while boasting reliability. Great emphasis is given to the possibility to deploying the sensor indoor, to monitor and manage crowds' activity. Like Aeva, Ouster uses Lidar on chip, without moving parts. However, it is based upon a different technology. Instead of deploying FMCW, Ouster uses a technology based on multi-beam flash Lidar using VCSELs and SPADs. These are two silicon-based microchips. The first one is a vertical cavity surface

emitting laser much like the flash of a camera. The latter is a photon detector chip for receiving the reflected light simultaneously. This architecture is supposed to increase efficiency, by sending and receiving at the same time beams of light only where they are directed.

However, contrary to Aeva, Ouster produces a rather impressive visualization of their sensor, with an animation that presents the device in a rotating manner, while all the components are deconstructed from the ensemble and the inner system of lens is revealed, before getting to the back-side illuminated core (see Figure 120, 121 and 122).

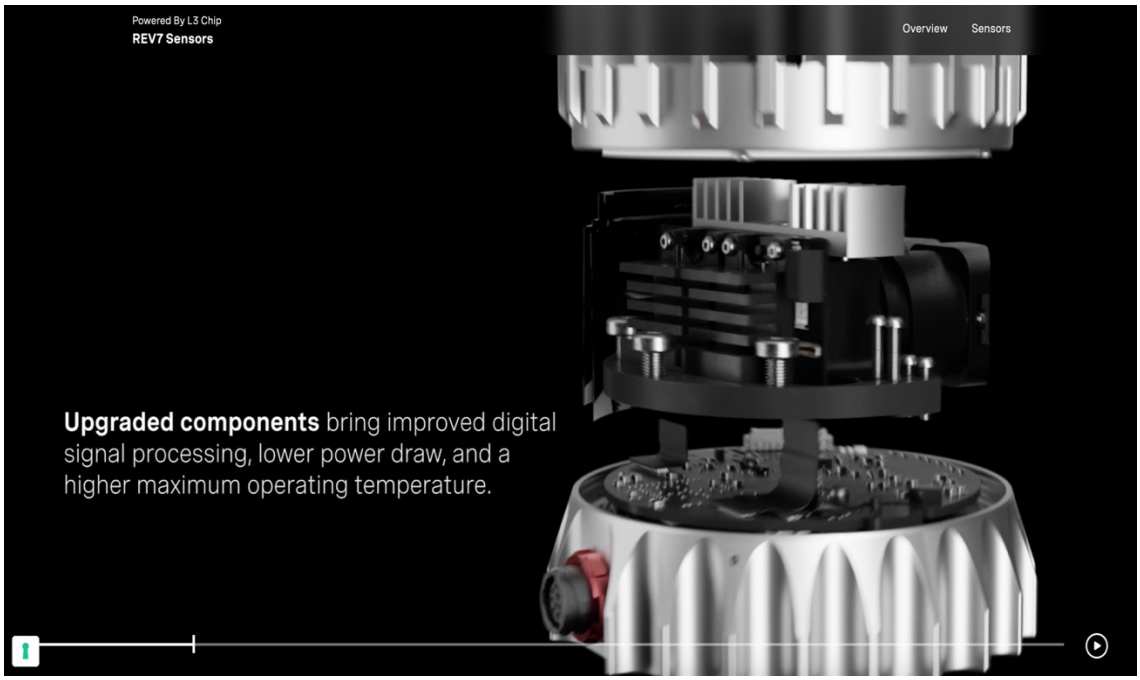


Figure 120 Series of screenshot taken to show the interactive graphic provided by the manufacturer to visualize the elements composing the sensor. https://ouster.com/products/hardware/osdome-lidar-sensor. Last accessed 20/09/2023

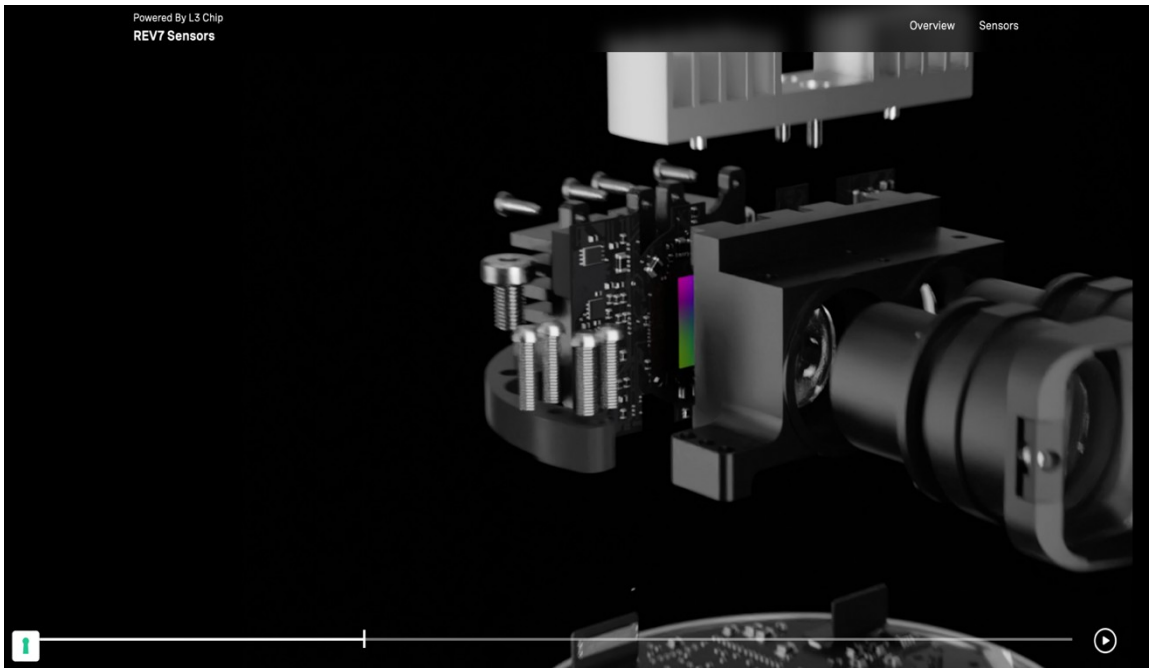


Figure 121 Second of a series of screenshot taken to show the interactive graphic provided by the manufacturer to visualize the elements composing the sensor. https://ouster.com/products/hardware/osdome-lidar-sensor. Last accessed 20/09/2023

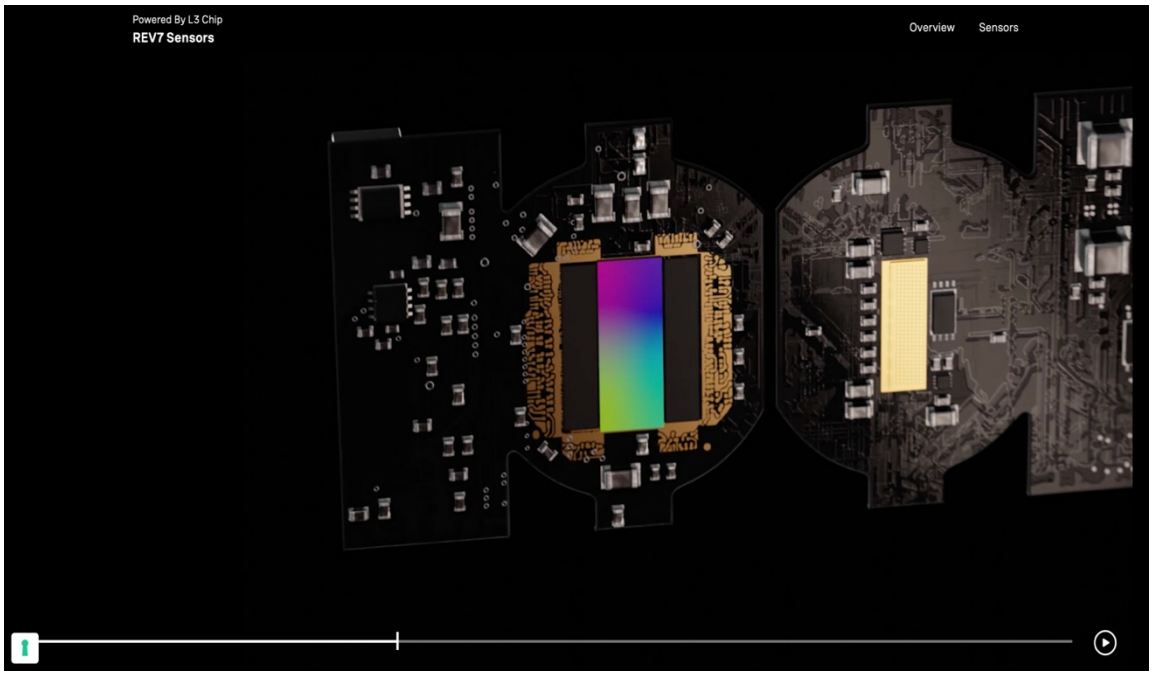


Figure 122 Third of a series of screenshot taken to show the interactive graphic provided by the manufacturer to visualize the elements composing the sensor. https://ouster.com/products/hardware/osdome-lidar-sensor. Last accessed 20/09/2023

Velodyne Lidar, since it has been bought by Ouster, has updated their website. Going to the "product" page, clicking on a bar on the top right part of the screen, the user can select a wide array of Lidar sensors, that represent an evolution from the first HDL-64E, as well

as the newer Lidar-on-chip. Exploring all these pages for each sensor, presents videos with animated galleries of the kinds of visualizations that can be obtained with the sensors. No explanation about the components of the sensor is provided. When clicking on the button "learn more", the user is redirected to a page that explains in detail how the proprietary Lidar data viewer works, and also makes available for the user a data-set to be tested in the provider's software (see Figure 123). It should be noted that currently this is the only company in the sample providing this possibility directly on the website. Ouster too provides their Lidar viewer for download, but I wasn't able to access the page through navigation on the website, it came up as a browser result after research. Both the software available for download from Velodyne and Ouster's websites is closed software, I do not possess the skills to "open them up" and, playing with data, describe and analyze how they work. However, both the applications are based upon an open-source software called ParaView. Scanning through the ParaView documentation[31] and forum page[32], it appears that the software is absolving different sets of tasks, all based upon the reading and visualization of CSV file format (a plain text that uses Commas to Separate Values to store tabular data). The main operations that can be performed on CSV Lidar data files are: filtering – using algorithms for filtering point cloud data, such as voxel grid down sampling, statistical outlier removal, and radius outlier removal; segmentation – using algorithms for segmenting point cloud data, such as region growing, Euclidean clustering, and connected component labeling; registration – using algorithms for registering point cloud data, such as iterative closest point (ICP) registration and normal distributions transform (NDT) registration; feature extraction – using algorithms for extracting features from point cloud data, such as normal estimation, curvature estimation, and feature histograms; finally visualization, that includes tools for visualizing point cloud data, such

[31] https://docs.paraview.org/en/latest/ Last accessed 29/09/2023.
[32] https://discourse.paraview.org/ Last accessed 29/09/2023.

as custom color maps of multiple variables such as intensity-of-return, time, distance, azimuth, dual return type, and laser id.

The open-source version of this program represents an interesting case study to analyze, to test and see if conclusions arising from the present set of evidence are confirmed. Moreover, it would necessary to design a collaboration with a media scholar as well as Python programmer, especially for visualizing interfaces.

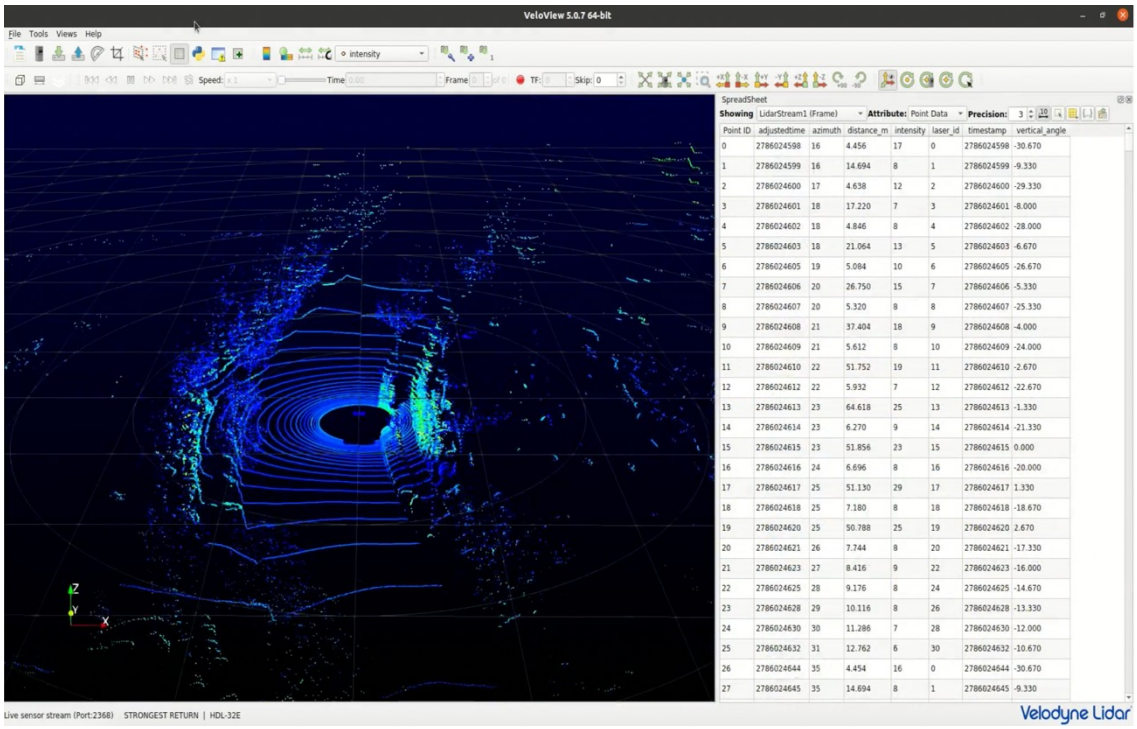


Figure 123 Screenshot taken from https://www.paraview.org/veloview/, accessible from a menu at the end of https://velodynelidar.com/products/puck-hi-res/. Last accessed 29/09/2023.

An addition to this, Velodyne exhibits a similar representation of their solid-state Lidar in a video analyzed in previous chapter, dedicated to the presentation of the Lidar series designed for last-mile robots (see Figure 142 and 125).



Figure 124 First of a series of screenshot taken from the YouTube video https://www.youtube.com/watch?v=jo4Iza4b0LI. Last accessed 29/09/2023.

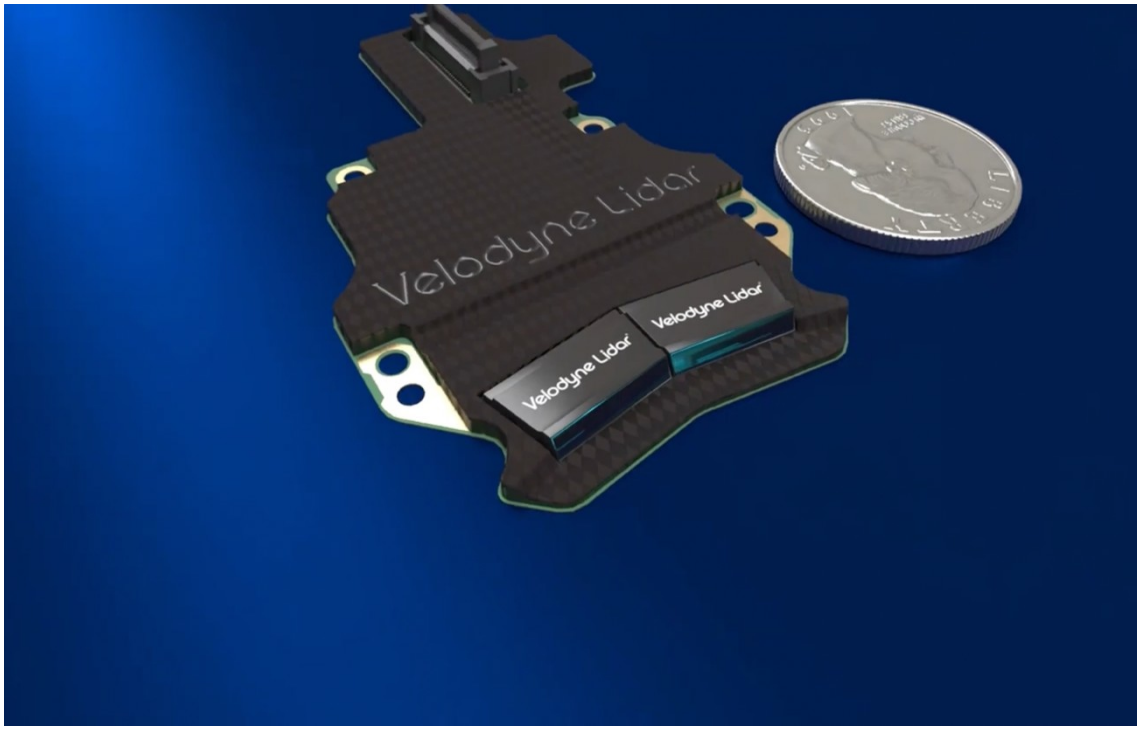


Figure 125 Second of a series of screenshot taken from the YouTube video https://www.youtube.com/watch?v=jo4Iza4b0LI. Last accessed 29/09/2023.

As seen in previous chapters, Quanergy is a Silicon Valley based company that proposes to be the champion of security and mapping for smart infrastructure, including, but not exclusive to, those concerned with mobility. The website is rather simple, composed of embedded videos and simple graphics, predominantly grey, blue and orange (see Figure 126). Clicking on the button "Products" on the upper-right bar on the homepage, leads to a sensor portfolio. The page for every product: a software and two different series of Lidar sensors, it's rather simple. The company advertises the device as a necessary component in industrial sites as well as the best tool for implementing surveillance. Clicking on the links available opens up a series of white papers, highlighting performances and relative benchmarks. However, the precise technology deployed is never mentioned. I was able to discover what kind of sensor is developed and sold by Quanergy only visiting the 2021 Investor Presentation page[33].

Reading through the document, I discover that Quanergy posits itself on the market of Lidar sensor as the only major company leveraging the OPA technology.

Optical Phased Array (OPA) technology is an innovative approach to Lidar, that is rapidly emerging to meet performance and cost requirements for autonomous vehicles and other mobile applications. OPA technology uses an array of tiny antennas to manipulate the direction of light beams in an OPA transmitter and the view direction of the receiver. This technology can manipulate the direction of light beams without using any moving parts, making it more reliable and cost-effective than traditional mechanical Lidar sensors: it's a form of electronic beam steering, different from the system based on mirrors and liquid cells mentioned above.

[33] https://quanergy.com/wp-content/uploads/2021/09/Quanergy_Investor_Presentation_09_21_2021-1.pdf Last accessed 29/09/2023

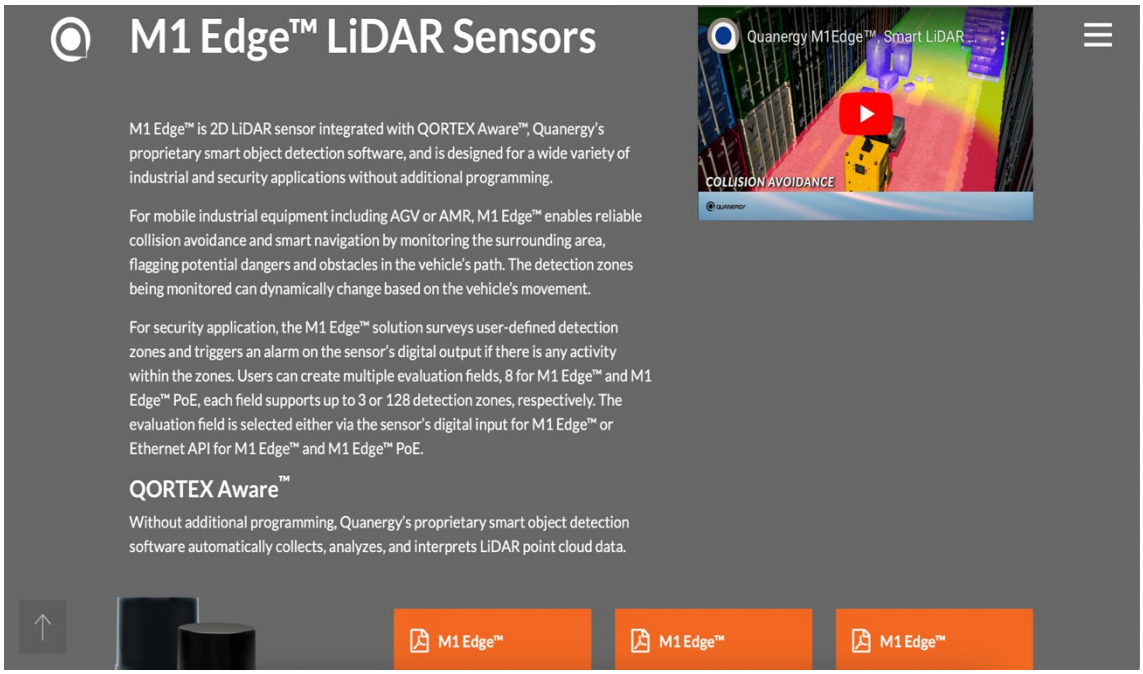


Figure 126 Screenshot taken from https://quanergy.com/products/m1-edge/. Last accessed 29/09/2023.

Innoviz, on the other hand, utilizes microscopic mirror mechanisms (MEMS) embedded on a chip to steer a single laser beam as it scans across the field of view (see Figure 127). As it appears from the dedicated page, the company underscores how their device has been approved by safety certifications. However, at the top of their page, the sensor is called "solid-state", a name usually referred to as Lidar-on-Chip, thus without moving parts. MEMS are actually semi-solid parts. They are miniature machines that combine mechanical and electronic components. They are fabricated using integrated circuit (IC) batch processing techniques and can range in size from a few micrometers to millimeters. MEMS devices consist of a combination of mechanical (levers, springs, membranes, combs, channels) and electrical (resistors, capacitors, inductors, etc.) components working as sensors or actuators. MEMS-based Lidar sensors are called quasi-solid-state Lidar as their moving parts steer only the laser beam in free space without moving any optical components.

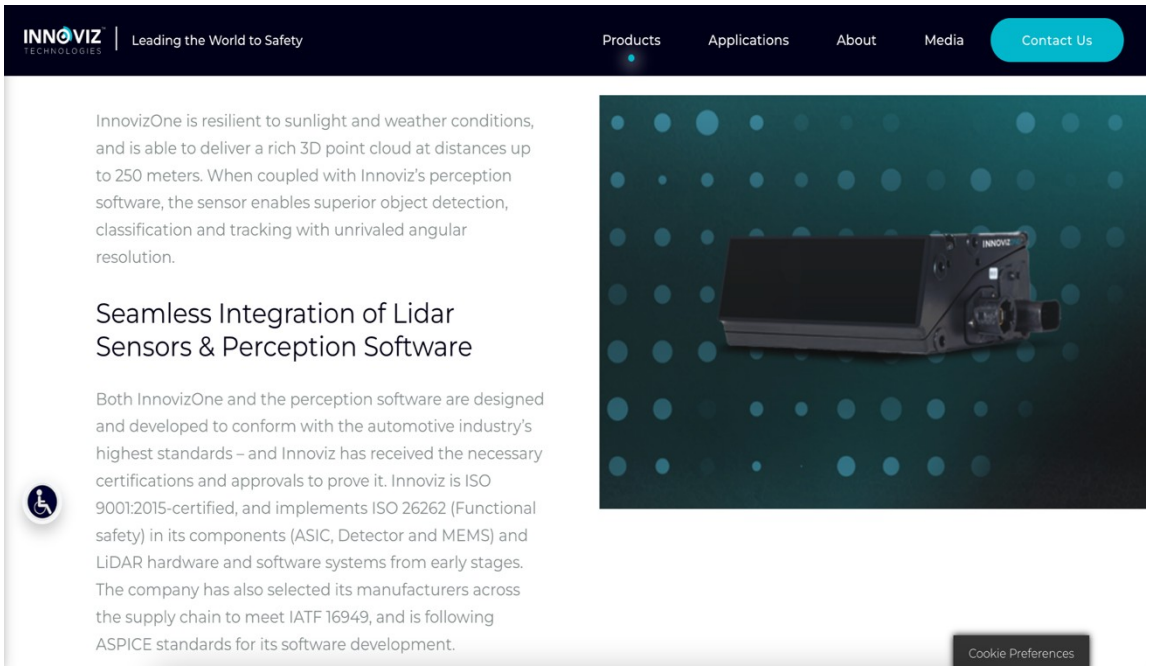


Figure 127 Screenshot taken from https://innoviz.tech/innovizone. Last accessed 20/09/2023.

Luminar's Lidar sensor is advertised as composed of all proprietary elements designed by the proprietary house -- including lasers, receivers, scanning mechanisms and processing electronics. Luminar's Lidar sensors are unusual, in that they operate at a wavelength of 1,550 nanometers, rather than the 905 nanometers customary for other sensors. This makes the laser bean safe for the eye, although it requires more electric power. The company also opted for a different architecture from traditional Lidar systems. Rather than using multiple lasers, Luminar uses a single laser that raster-scans a scene thousands of times per second, in a manner similar to the cathode-ray tube in an analog television. Luminar's Lidar devices combine the vision system and interpretive processing into one unit; other companies' Lidar devices require analog-to-digital converters to combine these systems. This happens because Luminar's devices use indium gallium arsenide (InGaAs) for their chips, rather than conventional silicon, so the sensors can operate at 1,550 nanometers while capturing light more efficiently. Indeed, InGaAs offers higher electron mobility and optical properties, so that the lasers can be

implemented on the same substrate as the computational element (Ajayan and Nirmal, 2015).

Since Luninar's Lidar sensor, Iris, has been designed to avoid waste in the deployment of a rare and expensive chemical compound used for transistors, the companies market their technology as ready for scalable production. Luminar also takes pride in underscoring how the high density of points – 300 per square degree, defined by them as "camera-like" – which allows for quick object detection and classification from software. Since cybersecurity is often a point in case against the safety of automated vehicles (Lee, 2017; Some et al., 2019), Luminar sensor is marketed as safe for unsupervised automation.

Luminar Technologies distinguishes itself from other Lidar companies in terms of design choices, down to the very materials composing transistors. Their distinction also appears in relation to the momentum of customer acquisition and engagement, which resulted in securing a series of platforms to launch the brand, compared to their competitors. As it has emerged from previous chapters, their website is designed in distinctly cyber ways, and it is also the most updated. Currently, the product page is no exception to this visual care. The page showcases the proprietary Lidar sensor and, as the page gets scrolled down, a zoom deconstructs the device in its components, while explanations appear to describe what the user is watching. Overall, the animation is fluid and ergonomic, it's rather engaging as well as informative (see Figure 128 and 131).

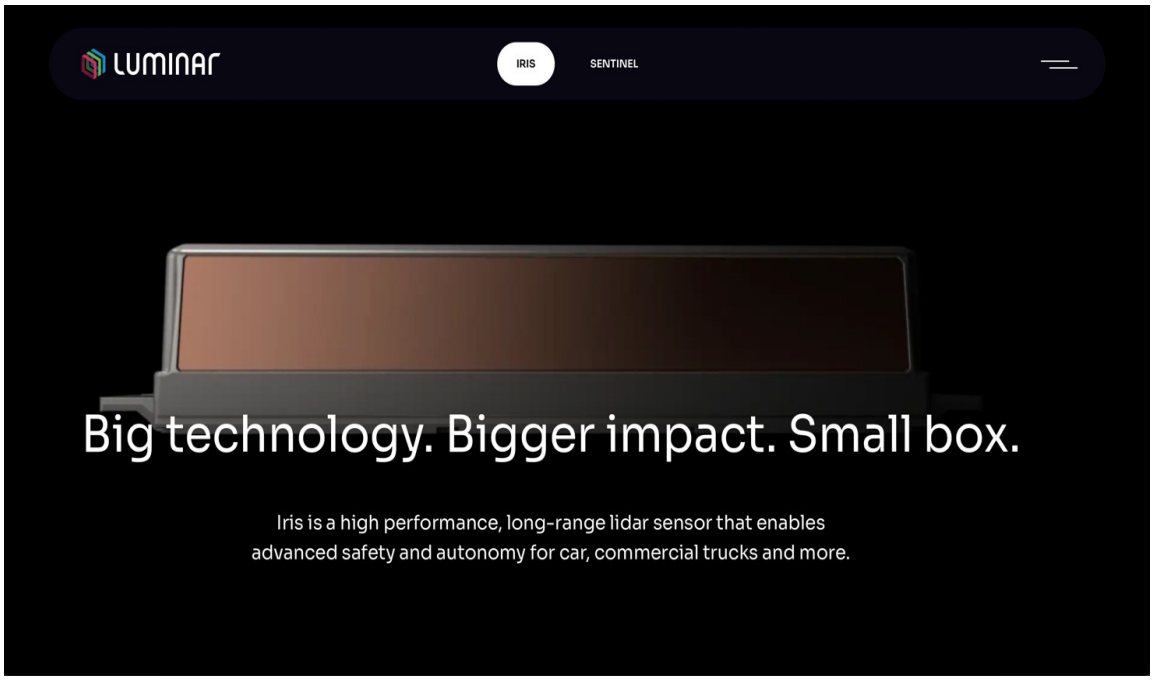


Figure 128 First of a series of screenshot taken from https://www.luminartech.com/technology to illustrate the interactive graphic work of the company. Last accessed 29/09/2023.

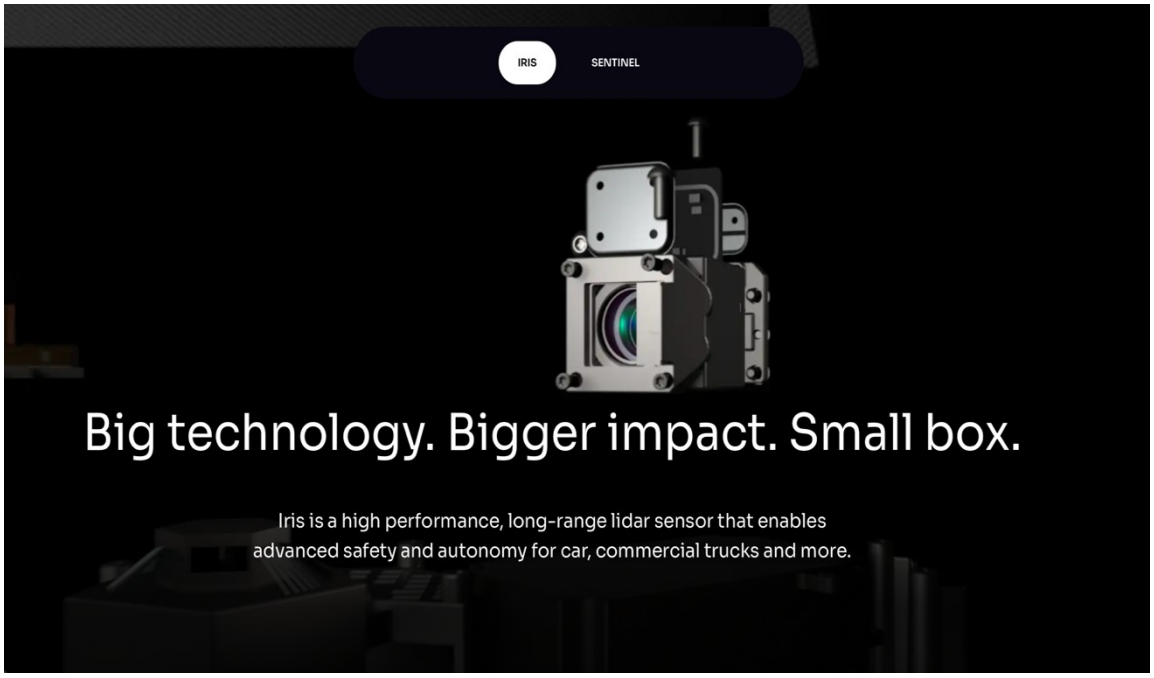


Figure 129 Second of a series of screenshot taken from https://www.luminartech.com/technology. Last accessed 29/09/2023.

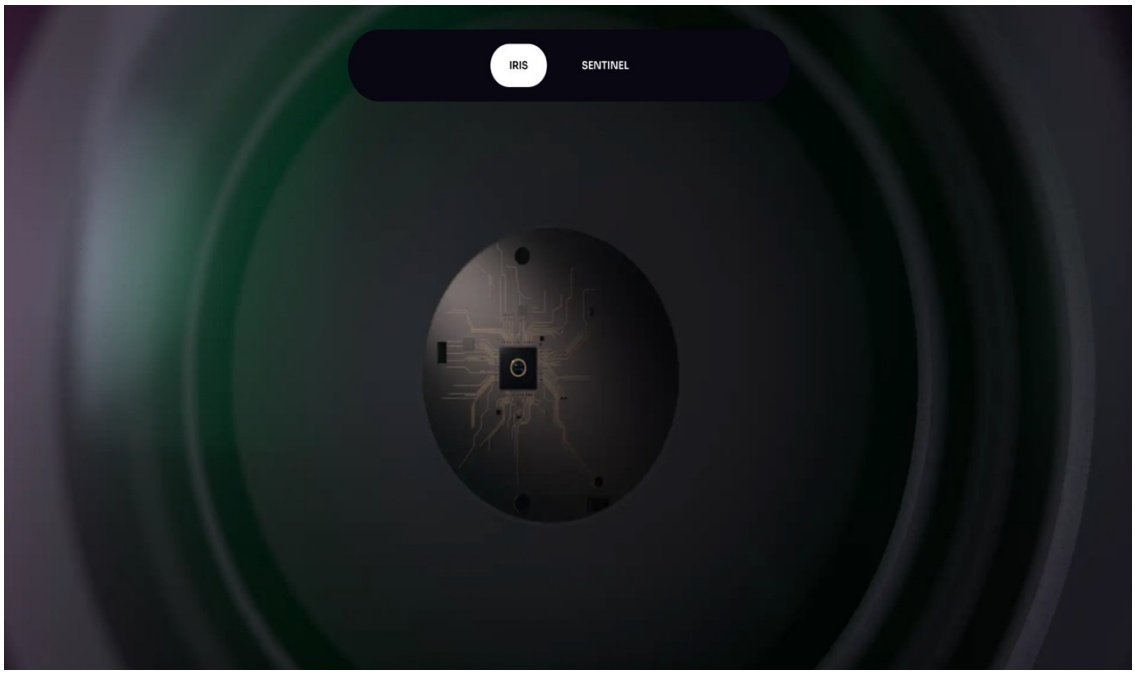


Figure 130 Third of a series of screenshot taken from https://www.luminartech.com/technology. Last accessed 29/09/2023.

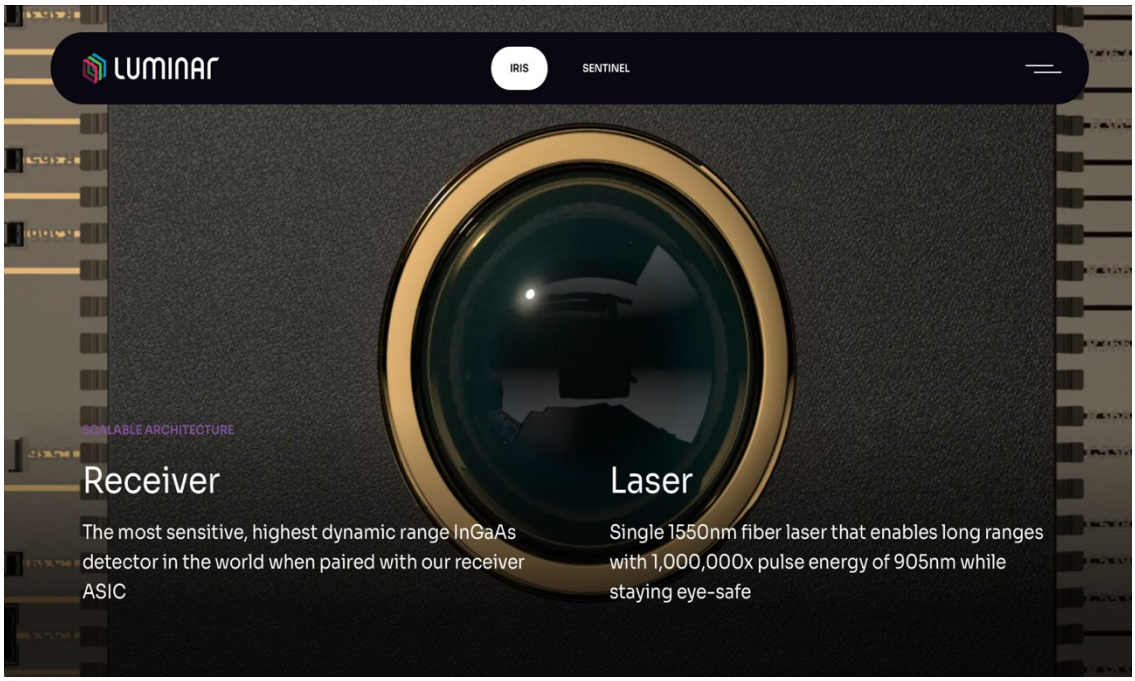


Figure 131 Fourth of a series of screenshot taken from https://www.luminartech.com/technology. Last accessed 29/09/2023.

Luminar is currently in partnership with Pony.ai, as we have seen, a global leader in autonomous mobility and is a pioneer in extending autonomous mobility technologies and services at a rapidly expanding footprint of sites around the world. Pony.ai operates

Robotaxi, Robotruck, and Personally Owned Vehicle (POV) business units (see Figure 132). The company underscore their data reliability, based on the redundancy of data extracted. Clicking on the page "Business", it's possible to find a part of the page that enlists the amount of sensors that the robotoxi deploys. However, I wasn't able to find further details.

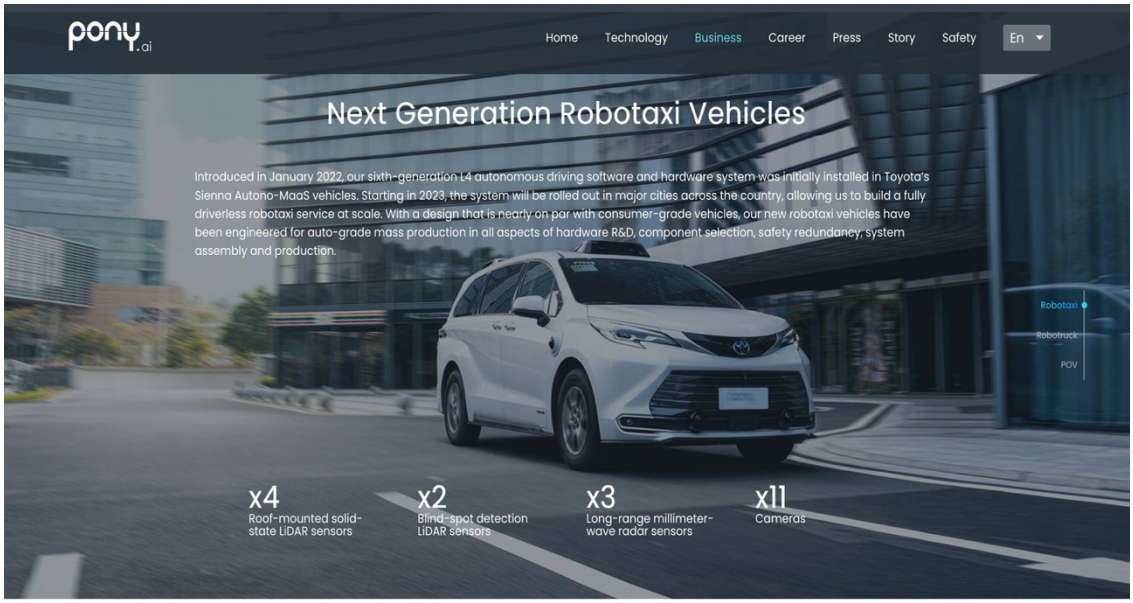


Figure 132 Screenshot from https://pony.ai/business?lang=en Last accessed 29/09/2023.

Recently, Pony.AI was in the midst of a crise, as operations in California were halted, due to a variety of safety concerns (including international espionage). The company was able to get a new permit, to start again testing with a driver present in December 2022, and actively started operations again in September 2023. It's also noteworthy that the Luminar material of choice for the production of chips is at the center of the so called China-United States trade war, which started in 2019 and it's ongoing.

As we have seen, all the companies presented here offer different hardware solutions for their sensors, and only two of them provided a clear visualization of the constitutive elements of the sensor. It also appears clearly that each and every feature examined here,

should undergo a much deeper and specific analysis, from the atomic levels, through the mineral level, to the stack level. Such work unfortunately here cannot be performed, due to internal coherence of the present chapter and adherence to the dataset.

The implications of these various approaches for Lidar technology are complex and not entirely clear. Scholars in the field are beginning to discuss the emergence of a post-optical (Agostinoh, 2019) or even post-lenticular (Parikka, 2023) phase in the development of technologically mediated perception. While Time of Flight (ToF) Lidar remains an optical device, based on its composition of lenses, laser diodes, and optical micromirrors, the status is currently less clear for FMCW Lidar. FMCW Lidar incorporates a low-phase laser and a set of microcircuits with an optical front-end and an electronic back-end on a single chip. The PIN array receivers perform Fast Fourier Conversion, transforming signals between the time-space domain and the frequency domain, and vice versa. The beams are, however, aimed at the surrounding environment through a lens and, as demonstrated, the principles being deployed are not different from those that have been at the center of scientific optical wars since the beginning of the scientific experimental era (Buchwald, 1989; Chen, 2013; Koiré, 1957; Levitt, 2009; Mamiani, 1976; Shapiro, 1973).

7.5 Discussion: Automating black-boxing

The methodological challenges encountered during the development of this research can be attributed to two primary factors:

1) Industrial secrecy, often manifesting as a general sense of mistrust among those involved in the field.

2) The clear difficulty faced by the chosen subjects in engaging in meta-semiotic discussions. This difficulty could not be easily overcome by simplifying the language or grammatical structure of the questions.

These obstacles compelled me to seek solutions that would bypass the limitations of language, recognizing the inherent challenge of verbal articulation. This challenge arises from both the imperfections in my own words and the broader context that shapes them. Despite these difficulties, it was essential to address the themes of this research, given the importance of this technology and its applications. If anything, these obstacles serve as tangible evidence of the absence of a digital public sphere, capable of engaging in competent discussions about technologies and their implications.

The deficiency in critical reflection has been examined by scholars in various ways. Cubitt (2014) has explored the normative function of visual technologies, highlighting how they present a hidden grammar that is not merely unconscious or black-boxed, but rather concealed like a trade secret. Similarly, Galison and May (2014) have proposed the concept of a "new episteme of secrecy," characterized by active concealment that shifts the focus from questioning why something functions as it does, to achieving efficient functionality without probing the nature of reality itself. These scholarly perspectives offer compelling arguments and numerous examples to support their claims[34].

To articulate this liminal space of epistemology, or its void, I turn to Deleuze's reading of the panopticon which, much like the Lidar sensor, is a tool for managing gazes, and

[34] However, the challenges encountered in interviewing individuals actively involved in this new episteme led me to recognize a lack of awareness that does not neatly fit into a conscious or unconscious state of being in the world. It exists in the liminal space between visibility and invisibility, transparency and opacity. In attempting to verbally grasp these new visual technologies, one cannot help but be reminded of the act of self-censorship inherent in the diagram of the unconscious (Freud, 1923/1989) and the underlying discomfort of civilization (Freud, 1930/2015).

is constituted by material patterns of knowledge and power, as well as the physical presence of light, lenses and mirrors (Semple, 1993).

> What can we call such a new informal dimension? On one occasion Foucault gives it its most precise name: it is a 'diagram', that is to say a 'functioning, abstracted from any obstacle [. . .] or friction [and which] must be detached from any specific use'. The *diagram* is no longer an auditory or visual archive but a map, a cartography that is coextensive with the whole social field. It is an abstract machine. It is defined by its informal functions and matter and in terms of form makes no distinction between content and expression, a discursive formation and a non-discursive formation. It is a machine that is almost blind and mute, even though it makes others see and speak.
> What is a diagram? It is a display of the relations between forces which constitute power in the above conditions: "The panoptic mechanism is not simply a hinge, a point of exchange between a mechanism of power and a function; it is a way of making power relations functions in a function, and of making a function through these power relations." We have seen that the relations between forces, or power relations, were microphysical, strategic, multipunctual and diffuse, that they determined particular features and constituted pure functions. The diagram or abstract machine is the map of relations between forces, a map of destiny, or intensity, which proceeds by primary non-localizable relations and at every moment passes through every point, 'or rather in every relation from one point to another'. (Deleuze, 1986).

Deleuze characterizes Foucault as a cartographer, someone who meticulously maps out the interplay between knowledge and power, particularly during the years spanning 1957 to 1969. One of the most renowned concepts associated with Foucault is the panopticon, a disquieting architectural structure that serves as both a map of gazes and a diagram of power vectors. However, this concept has posed significant challenges for scholars attempting to assign it a definitive philosophical meaning.

Deleuze's interpretation offers valuable insights into the ever-shifting nature of the *panopticon*. It is not a fixed image, or a metaphor inscribed into an architectural form. Instead, it represents the visualization of a power equation, encapsulating the asymmetries between the subject and the subjugated, as well as their dynamic qualities in terms of who wields power and, crucially, where it is wielded. The panopticon functions as a series of operational code strings authored by someone, hidden away, and then forgotten over time.

Much like the *Trojan Horse,* which played a pivotal role in the Greek victory, the panopticon disguises itself with an impressive outward appearance. However, within its seemingly benign exterior lies hidden malevolence, similar to malicious code ensembles, *trojans*, capable of surreptitiously eroding the hard drives of unwitting users while posing as beneficial and useful programs. Trojans are designed by hackers with initially undisclosed intentions but unmistakably hostile motives. Once online, they take on an abstract life of their own, circulating among computers in their deceptive guise, gradually consuming data, creating backdoors, and forging alternative pathways within databases and archives.

In this context, I argue that the epistemological gap can be likened to the trojan horse image: neither fully intentional nor entirely unintentional, it represents the automated result of a process of black-boxing, originating from an act akin to cyber warfare.

This covert act of warfare is encoded within visual technologies, with Lidar emerging as the latest development in this digitalization process. Terrestrial Lidar technologies collect data that is subsequently organized into a two-dimensional augmented map, representing a "slice" of a three-dimensional model. This mapping operation relies on a set of algorithms known as "occupancy grid mapping," originally designed in the mid-1980s for mobile robotics. These algorithms consist of probabilistic formulas designed to address the challenge of generating accurate maps from data collected in noisy environments (Moravec and Elfes, 1985).

As the name suggests, these algorithms create a dense grid overlaid onto the conceptualized space, with each point on the grid representing a location to be determined

as either occupied or unoccupied by an obstacle, represented as a binary variable. It is worth noting that Lidar, being a laser-based projection technology, scans the environment's surfaces using a symphony of photons manipulated to produce a scanning pattern that emulates the raster scanning inherent in contemporary visual display technologies and the spatial arrangement of pixels on such displays (Cubitt, 2015:95-100).

Furthermore, the data collected through Lidar technology is reorganized algorithmically, transforming incandescent light into laser light that is computationally manageable, in a sense, through the use of square waveforms. This transformation paves the way for the generation of maps based on binary language, facilitating the creation of a digital representation of the environment:

> The specific form of that coherence recurs at the smallest level: that of the wave- forms carrying digital signals through fiber optics, which now form the backbone of all our digital networks, integrated with the transmission protocols governing Internet traffic as well as signals passed between components inside discrete devices. This is the "square wave," which acts both as a clock signal and as the carrier wave for mes- sage transmission. Although we speak of digital media's units as zeros and ones, in reality zero current is all but unrealizable. "Zero" is a polite fiction for "small." The naturally occurring sine wave of light moves smoothly from crest to trough: the goal of the square wave is immediate and total transition from maximum to minimum value with no gradient at all. But neither electronic nor laser transmission can entirely eradicate graduations between states: they are simply ignored, averaged out of the equations (discrete Fourier transforms) used to convert sine waves to square. (Cubitt, 2014, p.225).

It becomes evident that Lidar technology is not merely the outcome of long-standing physical principles rooted in the laws of physics that gradually materialized through the discovery of suitable materials and the convergence of global experiments. It also embodies a desire for order that extends beyond space and time, encompassing the very light that illuminates our world. This desire for order is far from neutral or innocent. The occupancy grid algorithms, in fact, can be viewed as the latest iteration of older

algorithms that were employed in the practice of spatial mapping even before the advent of SLAM (Simultaneous Localization and Mapping). An example of such an algorithm is the SITAN algorithm (Campbell et al., 2003), which was originally used in conjunction with radar to calculate the topography of a region based on altitude comparisons.

SITAN, in turn, is an evolution of the TERCOM (Terrain Contour Matching) algorithm. TERCOM is designed for contour mapping, a technique that involves comparing radar data obtained in real-time with a pre-existing contour map, displaying altitude contours. By comparing these two types of data, TERCOM can determine the position of a flying vehicle (Golden, 1980). This technology has its roots in the cartographic practice of *isograms*, maps characterized by lines that define regions with consistent altitudes (Balchin and Coleman, 1967). The earliest application of this algorithm can be traced back to the ATRAN missiles developed in the 1950s, marking the first instance of ballistic weaponry equipped with geolocation capabilities—a pioneering effort in tracking and targeting through statistical and automated geospatial data.

As urban life undergoes digitization and archiving, it employs a technology originally developed for warfare purposes. However, the origins of this technology have been contained by educational and commercial institutions, concealed, and black-boxed, often hidden behind the veil of trade or political secrets. Consequently, the concealed intentions continue to be automatically reproduced without critical examination.

The logic of the Trojan horse adheres to a "neither/nor" logic, initially articulated by Schiller in his reflections on aesthetics and later employed by Rancière to formulate his concept of the "partage du sensible" (the distribution of the sensible) in 2000—a notion that encompasses the division of what can be perceived, thought, and acted upon in the

world, always implying a concealed political hierarchy. Dikeç (2015) was among the first to apply Rancière's ideas to geography, recognizing the significant role of space in his theory. Building upon this foundation, I would like to propose that the division of the sensible perpetuated by the visual technologies discussed here is fundamentally underpinned by a political economy of war[35].

The immediate concern associated with this concealed normative paradigm is that, as such technologies become increasingly ubiquitous—Mobileye, for instance, introduced a grassroots platform for pervasive mapping with Lidar at CES 2023—they are more likely to treat the urban landscape as a problem to be resolved (Zook, 2017). This approach transforms urban environments into a data lake, with countless tiny points placed on a grid to facilitate tracking, prediction, and potentially even targeting. Here, the digital materiality of Lidar becomes apparent in the way that, in mainstream media, it visualizes and makes present the virtual – and its visual output, while concealing what is physical, mineral, shower of photons, atomic dynamics and electronic impulses. This substitution of the physical/virtual, in the dialectic of what is visible vs. what is invisible, also fundamentally alters the hermeneutic relationship that constitutes the basis of the development of epistemic tool within technoscientific practices.

Turning again to Boyer (1996), we encounter a critical examination of the risks associated with drawing an analogy between cyberspace and the cyber-city. While deconstructing the overlapping images, Boyer acknowledges a glimmer of truth within the analogy: technology, both by design and error, seems to have projected onto the city

[35] Elden's work, notably the paper "Secure the Volume" (2013) advocates for a volumetric understanding of space, going beyond the understanding of areas, integrating the vertical axis, thus offering a new understanding of the entanglements between materials and scales in volumes, offering novel insights on warfare strategy. Also very close to my reading of the connection between aerial views, the production of algorithms and the economy of war is Dobson (2023).

the form of the mathematical matrix that constitutes its software core. She goes on to provide various examples of how this matrix captures and organizes the continuous flow of data, information, images, and capital. Building upon this, and considering my previous reference to privacy concerns, it becomes evident that through this anonymous targeting facilitated by laser-based technology, citizens themselves are apprehended through the lens of this flow.

In the automated process of implementing technological opacity – hinged on the dialectic of physical/virtual; visible/invisible – the relationship between the hermeneutic tool -- composed of materials and information resulting from the manipulation of materials, what Wiltse (2014) and Wellner (2020) call the substrate and the trace -- human users and the world to be experienced are slowly turned upside down. In my failed interview-based pilot study, I had the chance to realize that researchers working *with* Lidar imaging, for example in archeology or forestry, and engineers working towards the full automation *of* Lidar imaging had a completely different approach to the sensor – which was also reflected in how they were able to articulate their relationship with the tool verbally. Researchers working with Lidar had a form of embodied hermeneutic with the sensor: they were interested in working with the sensor to get the best information output towards their research goal. In order to do so, their relationship with data and the phenomenological world was constantly being calibrated and negotiated towards the reaching of the best result, in a form of human/non-human cooperation, in which boundaries and expectancies were well established. Engineers, instead, were not capable of articulating this kind of relationship with the sensor, nor its results. Their work was directed towards eliminating cooperation with the sensor, towards its full autonomy, whatever that might look like. This end-goal makes it so that the human and world parts of the equation that described the hermeneutical relationship were muted, towards a

complete foregrounding of the product of the sensor, the trace. The human user, or co-creator, and the world, to be experienced and modified, were elided as merely control tests for the trace outputted on the screen, making invisible the physical processes of the substrate, leading to it. The concept of Lidar digital materialities, here proposed, serves as an attempt to counteract the process of making invisible the physical world, which is manifested through the prevalence of the trace. This involves revealing the role of the substrate - namely the materials and their functionality - that enables hermeneutic processes.

On a more speculative level, the anthropomorphic view of prosthetic devices can limit the possibilities offered by machines. As demonstrated in the preceding analysis, recent digital advancements in mechanical systems replicate the physics of Icelandic spar (Kristjánsson, 2012), but in miniature form on a silica substrate. New technologies are actively capitalizing upon a set of materials and laws of optics that were discovered at the beginning of the Modern Era (Buchwald, 1989; 2008; Chen, 2013; Levitt, 2009), as such, they bring with them conceptions of space that project a model of the world, which translates a formal order into a material one (Farinelli, 2009:120-125). Coupled with software, these sensors generate data that can enable machines to perceive the world with a precision surpassing that of human eyes, effectively "revealing the unseen" (Lenoir et al., 2022). However, if the software is designed by humans to emulate human vision for the benefit of humans and under human oversight, the "beyond" is effectively severed from the operation. These sensors result from the redirection of light toward informational tasks, tightly bound to human vision and constrained by human comprehension of the world, as well as its standardization in functional spatial representation.

Disrupting this continuous optical evolution would entail allowing laser-equipped machines to unveil a new visual world that humans are open to perceiving. The recurring themes of safety, security, and statistical predictability serve as the Maginot Line against the insurmountable uncertainty inherent in the mathematics underlying machine learning. No patent or industrial secrecy can shield against the fact that phenomenological reality simply cannot be predicted. Machine learning is grounded in the manifold hypothesis of the bundle theory (Hughes et al., 1990), which posits that input data exist on a non-Euclidean manifold—a topological space that locally resembles a Euclidean space but may not be globally homeomorphic to it. The manifold is locally similar enough to a vector space to allow for calculus, but it may not be closed under summation, meaning that the sum of two points may not necessarily lie on the manifold (Goodfellow et al., 2016: 159-165). The manifold is an assumption, not a fact, and it can never be definitively resolved as such. No amount of algorithmic processing can bridge the disconnect between the space of calculus and the phenomenological space that needs to be modeled to extract statistical knowledge. From a different perspective, the issue of the manifold's dimensionality is akin to attempting to represent the Earth's three-dimensionality on a flat surface. However, since the manifold is impossible to directly perceive, the correctness of this hypothesis must be continually validated through statistical repetition (see Figure 133 and 134).

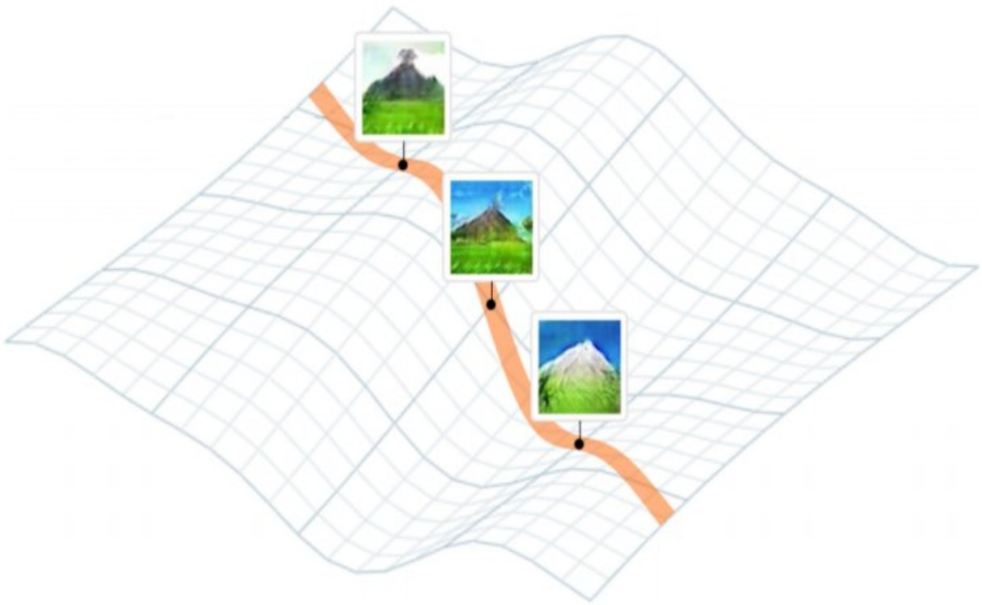


Figure 133 From the machine learning personal notes of one of my interviewed human subjects: their own rendition of the Manifold Assumption.

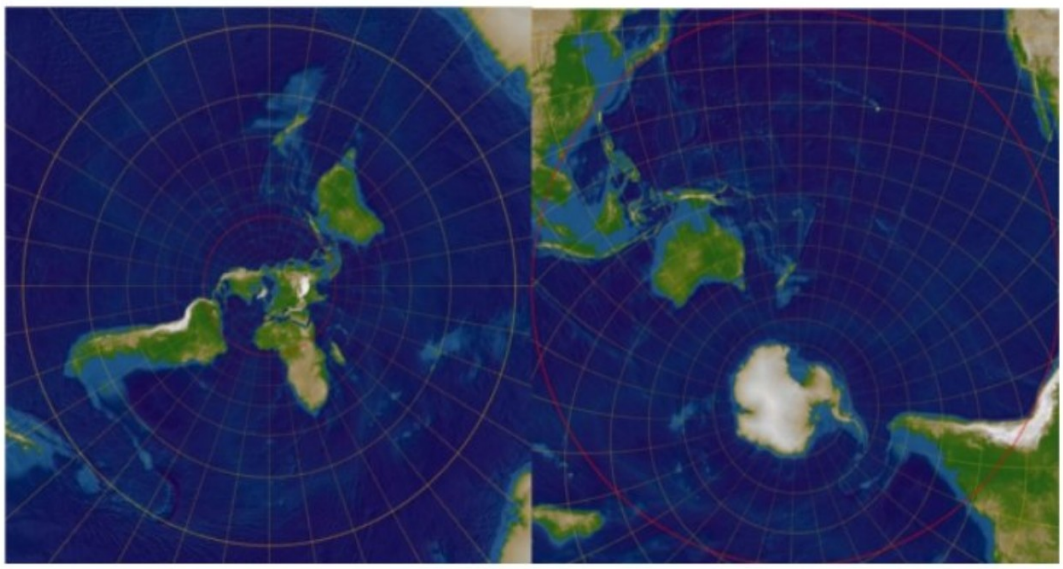


Figure 134 From one on the interviews with my human subjects, when asked to further elaborate on the manifold assumption, the subject provided the picture above, commenting: "The Earth is a manifold that can be represented with at least two charts".

7.6 Conclusion

In this chapter, I have delved into the historical evolution of Lidar technology, tracing its origins and the various developments it has undergone, including the ideas, materials, convergences, fractures, remembrances, coincidences, and experiments that have shaped it into what it is today. This genealogical exploration has revealed that Lidar technology shares kinship with searchlights, and other military purposes, and by extension, with cinema and spectacle, as well as with telecommunications.

Furthermore, I attempted to disassemble the Lidar sensor, to uncover the constitutive and phenomenological elements of the Lidar experience, once it is dissociated from the protective discourse that currently surrounds it. To achieve this, I have provided a description of the materiality that underlies the digital spatial management features specific to Lidar architectures currently available on the market.

While I have not been able to directly analyze the layer of software currently used in Lidar technology, I have offered a genealogy of spatial algorithms, which, in turn, led me back to the realm of war and war technologies. It is important to note that I do not view the grammar of knowledge and power inscribed within Lidar technology as inherently malicious. Instead, I consider it as the automated outcome of a historical gesture within the realm of technoscience—a gesture that aims to protect against the abyssal unknown by using the metaphor of grid-based space management.

In essence, I argue that the act of scanning space and modeling the environment, when combined through digital post-production for visualization, represents an attempt to purify space from extraneous events. This operation should not be solely attributed to the

technique or technology itself but rather to the automated aesthetics—an organization of the sensible and its possibilities—embedded within the materials, relationships, and processes that constitute Lidar technology.

Chapter Eight

From profiling to tracking

8.1 Introduction

As seen previously, the digital materiality of Lidar produces an articulation of space suspended between the planar and the spherical mathesis. However, it has also emerged implicitly how this sensing modalities is tied to time measurements, while producing new conceptualizations of temporalities. In this chapter I'm going to focus on this temporal aspect of Lidar sensing, but I will do so from the perspective of the relationship between seeing/being seen and the visualization of such non-neutral acts of seeing (Lyon, 2022), as it has been articulated in the Surveillance Studies field, in the Second Chapter.

According to Vukov (2016), post-racial claims, when linked to surveillance practices, are to be challenged. In her essay, she takes on as a case study the smart border between Canada and the USA. Technologies deployed at the border, while claiming to be blind to race, are encoding, in novel ways, racialized practices. Vukov starts by reporting how Foucault himself views race as a critical gap within biopolitics (2003): to let live a population implicitly means that the Other shall die. Mbembe famously thematized this as necropolitics (2011): to precisely underscore the systemic oppression of racialized communities in the management of the life of the population. Borders are physical places in which the discrimination between who is part of the population and who isn't appears, while bordering practices mobilize racializing practices beyond the border. Within bordering practices, forms of algorithmic profiling emerge as a key tool to prevent and intervene in real-time. Vukov lists and analyzes four specific sets of technologies that, through data collection and data inscription upon selected targets, reshape the working of

race: "technologies of bioembodied inscription; movement sensing and geolocation; autonomous machinic technologies; and algorithmic data assembling and storage" (2016:85).

Lidar sensors can output visualizations capable of positing them in what Vukov defines as "movement sensing and geolocation", as well as in "autonomous machinic technologies", as they are both related to drone technologies and are based on rendering spatial relationships, instead of visual features. Vukov explains how movement-based technologies are obviously deployed along routes and lines that are suspected to be traveled by already racialized subjects, and moreover, data training can detect what are coded as abnormal conducts. Referencing Parks (2014), social sorting becomes the vertical axis along which discrimination is codified anew. The possibility of autonomous movement from targeting sensors opens up the possibility of panoramic views and micro-detailed explorations along these new lines of "paranoid visualization"(p. 92).

In this chapter, I'm going to analyze the shift exhibited by many Lidar producers towards an increased focus towards surveillant practices. After the presentation and analysis of the materials, I will discuss a literature around time and temporalities in human geography. I will then present the concept of *flow* and proceed to describe a conceptualization around the shift in the biopolitics of security afforded by crowd management, highlighting risks for racialized encoding. After this, in the Conclusion, I'll summarize my findings and discuss some positions from scholars that have been studying computer vision and machine learning and what computational processes entail for objects and images.

8.2 Instances of dual-use technology

I will now start looking at different declensions, through their online and spectacular presentations on websites, social media and technological fairs, of crowd surveillance and how it is differently deployed by AEye, Aeva, Innoviz, Luminar and Ouster.

Looking at AEye's site, there is no mention of the possibility of devolving the proprietary hardware and software stack for surveillant purposes. Crowd management is not specified in any way, and it looks like *every kind of semantic choice* that might be traced back to activities connected to monitoring has been avoided. For instance, in the branch of the site dedicated to the applications of their technology, "Solution", under the voice "Smart Infrastructure", after the paragraph explaining how Lidar sensors might help in managing intersections and toll gates for the highway, while humans appear as stickmen in the graphic designs accompanying the text, the biggest headline, summarizing the features of the technological stack within this specific application, recites "Signaling a change"[36]. This simple and neutral wording describes the main goal of the sensor: to track the environment to detect anomalies and allow the machine to take informed decisions to solve mobility tasks. As noted, the functioning of the stack of hardware and software is described in very simple and flashy terms, that summarize efficiently the core of the tasks, without conceding space to either positive or negative potentiality. This kind of descriptive and efficient communication style can also be seen in the "Rail"[37] section, another option among the "Solutions" that Lidar sensing might provide. In this section, along with the aesthetic choices typical of these specific companies, already seen in Chapter Five and Six, we can appreciate, in the efficient, concise although careful, wording already seen in the previous example, how Lidar in railing can be used to "from asset inspection to collision avoidance, shunting, and full

[36] https://www.aeye.ai/solutions/lidar-for-smart-infrastructure/ last accessed 25/7/23.
[37] https://www.aeye.ai/solutions/lidar-for-rail/ last accessed 25/7/23.

system autonomy". Here we can appreciate once again how the wording summarizes, without giving too much detail, the functions of the sensor. How the graphic next to this explanation portraits, Lidar sensing can be used to detect objects obstructing the railway. In the next paragraph, the explanation progresses in describing how the modularity of the architecture of hardware and software provides a solution for every space connected with trains and railways, producing here a practical example of the kind of "universality" advanced as a central category in the discourse around Lidar sensing (see Chapter Five). However, at the end of the paragraph, the explanation provides some more details about the application of Lidar sensing in train stations: "a single 4Sight Lidar sensor mounted on a revenue train can address several use cases simultaneously, such as collision avoidance, asset inspection, and platform monitoring as the train approaches the station, making it the most adaptive and cost-effective sensor solution for rail". In this instance, monitoring is *clearly stated* as one of the main features of adopting remote sensing for managing rails.

The interest in the management of rails is especially important when contrasting this application with the Israeli company Innoviz. Exploring the company's website, there is no *explicit* trace of any kind of surveillance activity. The "Applications"[38] page proposes a list of fields in which Lidar sensing might prove to be critical. The list includes: Consumer Vehicles; Delivery Vehicles, Robotaxis and Shuttles; Trucking; Logistics; Sidewalk Delivery; Industrial Drones; lastly Heavy Machinery. In none of these pages crowd management is mentioned. The preferred wording pertains to the main functions accomplished by the architecture composed of Lidar hardware and perception software[39]: "Object Detection, Classification and Tracking". This, in a style slightly more direct than AEye's approach, describes how perception is accomplished through hardware and software and towards what goal. Objects are modeled with a point cloud and then

[38] https://innoviz.tech/applications last accessed 23/7/23.
[39] https://innoviz.tech/perception-software last accessed 23/7/23.

analyzed through software. The main goal of the software is to provide a categorization within the mass of raw data included in the point cloud, thus "segmenting" – a technical term – the point cloud according to a pre-determined taxonomy of objects[40].

Semantic segmentation is indeed one of the main tasks in computer vision: the main task to accomplish is represented by assigning each pixel to one of the predetermined categories. The result of the task is constituted by a segmentation map of the image to analyze. However, the segmentation task in Lidar is not performed on pixels, which are the constituent elements of how Lidar data is *visualized*, but on Lidar *points* (Hasecke et al., 2022). Semantic segmentation with 3D Lidar images is especially challenging as it involves human work in manually semantically describing areas of the spatial model according to smaller units: from single point to clusters of points. Only later is the machine learning algorithm deployed to apply the human made semantic annotations to the other Lidar frames of the model (Mei et al., 2019) to track moving, already classified, objects. What's relevant in this technical, and exceedingly broadly portrayed, process[41] is the act of mapping a sequence of images – a flow of data that results in subsequent frames – which is the result of a projection of a schema constituting the worldview of the human operators designing the categories to be mapped upon the image. Complicating this conceptual work of mapping, is the fact that, as seen in the previous chapter, the image to be mapped is the result of spatial operations that output a visual rendering, in a constant movement between input and output: environment, data and modeling of the data. The result is something that goes beyond visuality – and therefore representation – but still presents itself through a visual medium. As shown in the previous chapter, the manifold theory constitutes the ground for these weird ontological fluxes, but it cannot provide

[40] https://innoviz.tech/wp-content/uploads/report_frederik_hasecke.pdf White paper published by Innoviz, based on Hasecke et al. (2022). Last accessed 25/7/23.
[41] There are several different methods to carry out the task here explained: see Hao et al. 2020.

complete mathematical certainty. However, engineers (Hasecke et al., 2022:599; Mustikovela et al., 2016) believe that data mined and processed through various methods can afford "ground truth" – in remote sensing, the phrase indicates the capability to link the output of a sensor to the "surface context" (Steven, 1987)[42], thus giving objectivity to statistical models.

In this game between points, spatial and visual, and mapped environments, in the quest for modeling the truth of reality, as Lidar producers emphasize *through their phrasing*, Innoviz provides the easiest description to understand one of the central problems represented by computational processes: "Detects objects with high precision. Boasts two independent detectors for identifying objects (i.e., cars, trucks, motorcycles, pedestrians, bicycles) as they appear through their shape and other attributes, and due to their movement. It delivers both high-quality object detection as well as more advanced object tracking (the ability to designate the same object as such in consecutive frames)"[43]. In a single paragraph, the company fuses together the process of object classification and the temporal nature of the tracking activity. It's important to note how, falling within the same parenthesis and thus grouped together, appear inanimate objects as well as humans, here identified with the functional identification of "pedestrian". In other words, in the process of tracking "objects" – everything in the environment – across time and space to allow for the machine to make decisions pertaining to its mobility, humans are considered an object among the others. As they fall within the field of view of the sensor extracting point-data, humans lose their human quality to be identified, within the space-time matrix of the data extraction process, as pedestrians.

[42] "Ground truth" is also the name of the sensing system deployed by Nissan. "Ground Truth" has also a significant meaning for the geographical community, as it is the title chosen for a collection of essays edited by John Pickles in 1995, thematically problematizing the advent of Geographical Information Systems for their social effects.
[43] https://innoviz.tech/perception-software last accessed 27/7/23.

This is the first important point, that will be properly developed in the Discussion part of this chapter. The second important thing to note, here, is the specificity of the distinction between AEye and Innoviz: neither of the companies refers *directly* to crowd management and surveillance, however, hints of the capabilities in this sense of the sensor manage to escape the careful and concise wording of the companies. Another difference between the two companies is that AEye *explicitly* mentions the application of Lidar systems in the management of railways and rail stations. Innoviz doesn't. However, visiting the Facebook page of the company, a post published the 18/7/23 announces the testing of Innoviz Lidar system at stations "to monitor pedestrian traffic & railway safety"[44] (see Figure 135). The brief video supporting the announcement explains visually very well how Lidar sensors might help in avoiding accidents caused by human negligence in station: like throwing objects in the railway or getting too close to the safety line. However, here a language of suspicion is introduced. This idea of suspicion connects that intensive but anonymous Lidar tracking to older profiling practices, as hinted at in the introduction to this chapter. However, this is not the only specificity of the discourse around Lidar: the framing of humans as pedestrians, perceived and categorized in the technical processes previously described, also presents cultural and ontological problems that will be further tackled, with the help of geographers and media scholars, further down in this chapter.

[44] https://www.facebook.com/InnovizTechnologies/ Last accessed 22/7/23.

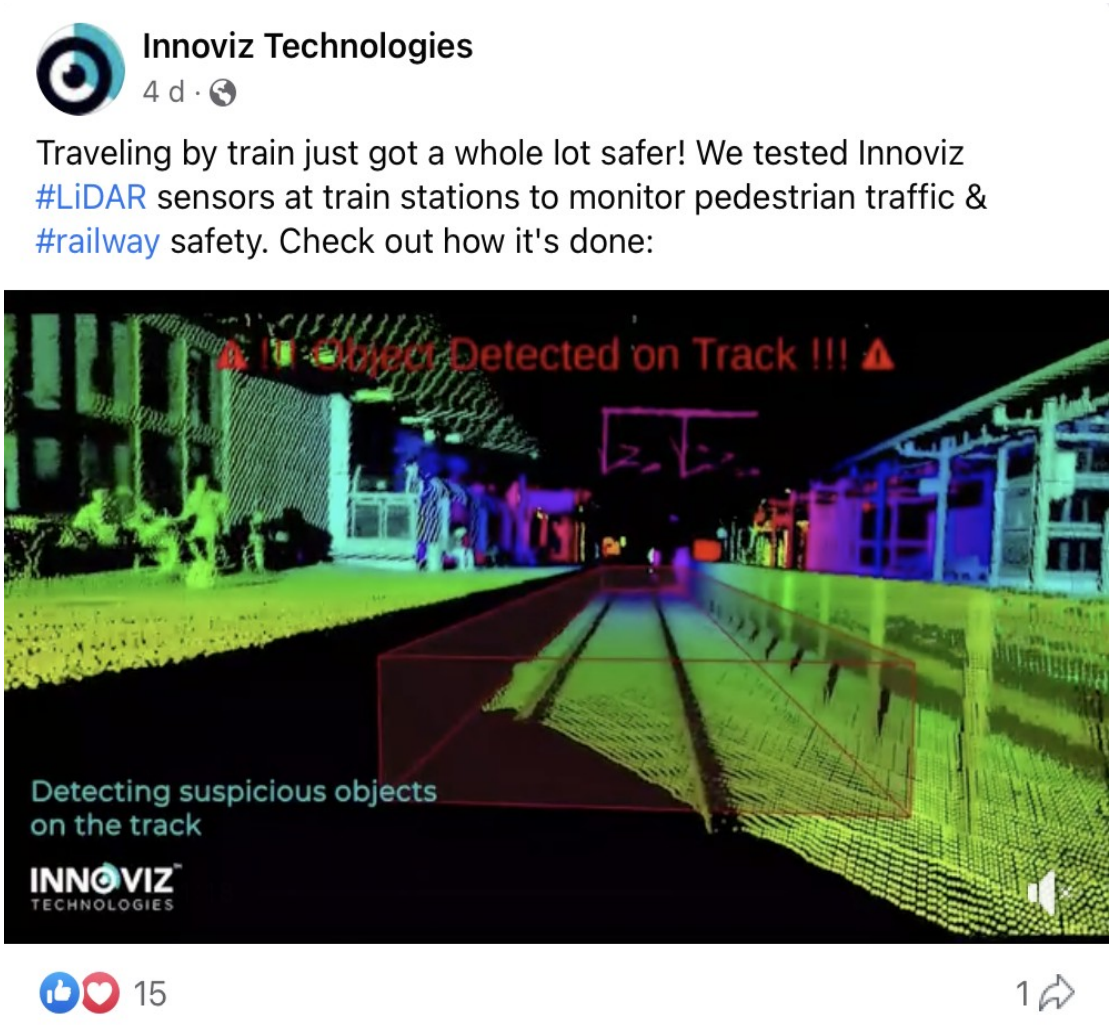


Figure 135 Screenshot from the video embedded in the Facebook post of Innoviz about railway surveillance. Site available in note 43.

Provisionally, it is worth noting how the idea of managing crowds in specific places that form a sort of space-time matrix that alters the ontology of humans is further pushed by another Facebook post by Innoviz, this one is dated 21/7/23. This post boasts the application of Lidar sensing beyond mobility and links it directly to an analysis concerning the deployment of Lidar in airports. The article linked, titled "How Lidar Improves Airport Operations", a comment by Digital Mortar CEO Gary Angel on the Airport Magazine[45], in which Lidar sensors are described as radars working with light, thus providing a radar-like image that grants the privacy of sensed humans. The

[45] https://www.airport-technology.com/comment/how-lidar-improves-airport-operations/#catfish Last accessed 22/7/23. The article was published on 12/7/23.

technological precision, along with its "nearly perfect" (Angel, 2023) performance from a privacy point of view, make it the elected sensor to be deployed in airports for "measuring people, not things" (Angel, 2023). In the process of explaining the action of "people measurement in very large spaces" (Angel, 2023), the author links back to an article in the same magazine highlighting how Blickfeld, one of the companies I flagged as interested in the smaller perceptual scale in the sixth chapter, has been repurposed from the automation of industrial sites to "crowd management and control" (Youd, 2022) in airports[46]. This links the idea of "*measuring people"* with the more established, but not widely researched from a critical perspective, branch of *crowd management*, a subgenre of surveillant practices (Kanaujiya and Tiwari, 2022; Valera and Velastin, 2005; Wijermans et al. 2016).

What is also interesting to note here is how, in the larger survey conducted in the fourth chapter, emerged the weirdly produced scale related to the sensing the interior of rooms – to automate industrial sites or to produce architectural renderings, or to produce a real-time scan of the interior of a car – and especially through the technique of face tracking, to allow automated support to kick in when the attention span of the driver visibly declines. In that survey emerged how only a small percentage of companies were advertising the production of such a smaller scale, compared to the usual scale at which Lidar imaging has been historically deployed: to map regional changes. Only through the industrial attempt at automating driving the scale at which Lidar has been deployed focused on metropolitan areas and then on the inch-by-inch mapping of individual roads and alleys,

[46] https://www.airport-technology.com/features/sensing-the-surroundings-blickfelds-lidar-technology/ Last accessed 22/7/23. It's also interesting to notice how in the article the pandemic of COVID-19 is pointed at as an accelerating factor towards crowd management. During the survey conducted for the Fourth Chapter the idea of deploying Lidar to ensure social distancing emerged in two instances, but it was not significant enough as an occurrence to be used as a discerning category. I choose to categorize the production of scale as a significant formal distinction towards the deployment of Lidar for monitoring people, instead of mapping what might have been one of the ancillary factors that favored this specific application.

in which, as we have seen, humans appear as pedestrians captured in an algorithmic matrix.

When it comes to the space-time matrix in which humans become pedestrians, AEye presented at CES 2023, the annual digital fair presented by the Consumer Technology Association, that was held between January 5th and 8th at the Las Vegas Convention Center, an immersive VR installation to "experience how vehicles sense the world in motion"[47]. The press release explains how AEye presented at Las Vegas an immersive installation through VR Visor and mobility joystick to walk *inside* a point cloud, as well as a sensed pathway and a ride in a minivan equipped with the Lidar sensor[48] (see Figure 136). Before proceeding with a more detailed presentation of what the AEye booth had to offer at Las Vegas, the press release insists upon the well-known idea of safety, one of the central categories in the discourse promoting Lidar imaging. AEye, in this instance of safety, describes how mortality on the road has been spiking, in the last couple years, quoting a study from the United States Department of Transportation. According to AEye, the installation is aimed at showing off how Lidar sensing, with its specific sensing modality, can guarantee safety for pedestrians as well as highway users of any kind, to "future-proofs autonomous development". It's interesting to note here how the category of temporality, which often expresses itself through an idea of futurism, is paired here with the category of safety, confirming what has been observed in previous chapters. However, the description of the installation provided by AEye goes a bit further. While

[47] https://www.aeye.ai/press-releases/aeye-announces-groundbreaking-immersive-lidar-experience-for-attendees-at-ces-2023/ Last accessed 25/7/23.

[48] https://www.youtube.com/watch?v=eY9O6QfSClA This is a video released by the company about their installation. It's really brief, but the flashes of point clouds available on the screen show the parted screen space that we have encountered in previous chapters, favoring a comparison between the world seen through camera eyes and the world seen through Lidar. Unfortunately, it's not possible for me, at this time, to provide a deeper critique of the installation as the visual material from it haven't been made available. Moreover, a VR installation is characterized by its immersive feature, something that would require direct experience, instead of a simple comment on the visual provided through the visor.

the VR installation represents the star of the show, so to say, "to see first-hand how Lidar accurately captures information about the 3D world", the monitored crosswalk is thus described: "Walk through a live, Lidar-monitored crosswalk to see how adaptive Lidar works in real-time to identify and track pedestrians in a zone in order to improve crowd monitoring and enhance pedestrian safety"[49]. In this description crowd monitoring is posed as a reality already in place that needs to be strengthened, in the name of safety. We also find again the idea of the pedestrian that is constructed as such when traveling through the *zone*, a different name from what I've been calling up to this point as a *space-time matrix*. The reference to zoning is obviously of immense importance for human geographers and urbanists alike, as it echoes historical processes of discrimination through space in the urban site[50]. After presenting the booth at CES 2023, AEye concludes the press release with a long paragraph explaining how, according to USA law and abiding by it, the press release is solely to be intended as a "forward looking statement", and, as such, is worded in a certain manner, conveying the enthusiasm that can be allowed at the time of the writing of the piece. However, continues the warning, none of the content present on that page should be taken as a binding statement, as risks and uncertainties around Lidar technologies, especially because of external factors like economies and the COVID-19 pandemic, cannot sustain certain projections of trend, and cannot promise the realization of the safety-relief that is usually considered one of the main driving factors in the development of automation. This warning clause also specifies that, nonetheless, AEye is completely in line with their reporting with U.S. Security and Exchange Commission.

[49] All quotes are from the press release linked in note 12.

[50] On zoning as a racial device within cities: Silver (1991) discussed how zoning was purposefully used in the USA in the first four decades of the 20th century to aggregate the black population in specific areas of cities. Çelik (1997) accounts for the spatial divisions inscribed in the landscape of Algiers in 1930 that will lead to a violent uprising ten years later. Le Corbusier's plans for the city are especially put under scrutiny.



Figure 136 A screenshot from the official AEye video about the multiple installation in the booth of the company at CES 2023. Available at https://www.youtube.com/watch?v=eY9O6QfSClA Last accessed 24/03/2024.

Looking at this report, one thing that emerges is, for example, the one filed by Aeva[51]. At page 67 of their report for the second trimester of 2021, the company clearly states, among the purposes of their product, the security of sites that are traversed by large crowds. The company enlists among those shopping malls and airports, and, along with this security, smart cameras equipped with Lidar sensors can also be useful in optimizing commerce. The paragraph goes on to describe how smart cameras are also becoming an in-demand request for the protection of private houses and homes, as they don't present concerns for privacy and are able to detect intruders from a long range and in complete darkness. It's important to note that on the proprietary site of the company, this focus on commercial and private security never emerges. The different fields of applications are not mentioned in the site, which is primarily focused on the development of Lidar-on-chip for the

[51] https://d18rn0p25nwr6d.cloudfront.net/CIK-0001789029/79c43478-550e-4048-b0f6-d57cced88132.pdf Last accessed 26/7/23.

development of autonomous driving. Only a shot in the headliner of the site, which has already been described in Chapter Seven, hints towards this crowd management inclination in the production of Lidar-on-chip.

CES 2023 really offered a spectacle, when it came to Lidar companies. Luminar, one of the most famous – and most colored, as we have seen in previous chapters - participated as well, putting up an interesting show for the lovers of speed. During the night of the 6th of January, indeed, Luminar invited investors to watch live a race car equipped with Luminar sensors speed racing through the Las Vegas Motor Speedway. The demonstration was called "Friday Night Lights out", as the main purpose of the spectacle was to showcase how Lidar can enable vehicles to see in the dark. The act of watching a car blazing through the night at exceedingly high velocity was enhanced, with the typical cyber aesthetics, from the application of neon stripes to the car, truly making it into a luminous bullet cutting through the night. This cyber-boostering show seems to respond to a common critique towards automated vehicles, about how safety can be only achieved at low and moderate speeds (Brown, 2017), as well as providing an enticing visual incantation showcasing the power of technoscience through speed and the muscular design of the racing car (Salter, 2014).



Figure 137 Screenshot from Luminar official video portraying key moments in the Friday Lights Out show. Available at https://www.youtube.com/watch?v=uVF_JVhOrU4 last accessed 24/03/2024.



Figure 138 Another screenshot from the same video, another take on the classic visual trope of the engineer working at the computer. Surveilling the correct working of the perception stack.

However, beyond the flashy neon lights, the spectacle of the speed of tomorrow, Luminar had even more substantial revelations to showcase at CES 2023. During the panel presented by the CEO of the company, among the presentation of the new Volvo EX 90 with the integrated Luminar Lidar sensor, as well as the milestones achieved in the previous year and the whole rebranding of the company, the main visionary goal of the company was also presented. Indeed, Austin Russel presented the production of digital maps as the central core of Luminar. Directly putting his company in the tradition inaugurated by Mercator, and then brought forth from the 2000's with the commercialization of mapping by Google, Apple, Here and Tom Tom – joking on the "millennial jump" – the director of the company presented his main project for the decade ahead: creating a "holistic map" of the whole world. "A true comprehensive understanding of the world", with "everything going on, an up-to-date map"[52]. In order to achieve this "ambitious", "aggressive" project, the company has already bought Civil Map, an important mapping company, and HD maps from Tokyo, San Francisco and Berlin, iconic urban squares representing the merging of technology and edginess, were shown on the screen. Nonetheless, it is important to note how the way forward in achieving this feature in mapping, this epochal shift in cartography, will be centrally powered by a paradigm difference from the current winner in the commercial mapping game. While the colossuses already mentioned deploy a fleet of vehicles enhanced by mapping devices and driven by employers of the company, the Luminar holistic map will be created by crowdsourcing all the proprietary sensors in every car equipped with it. This project is also described succinctly and in a more descriptive manner on their website: "A growing ecosystem of Luminar-equipped vehicles on the road enables data collected on real miles driven, which feeds an ever-growing data lake for enhanced HD maps and

[52] https://www.youtube.com/watch?v=bh3kmH3Bdng 7.25 - 15.37. Last accessed 19/7/23.

globally enhances the vehicle's performance"[53]. Interestingly here the global vision of mapping the whole world breaks free from the interest in the urban site or in a specific site or zone that works as a space-time matrix to frame traveling humans in a certain manner[54].

At CES 2023, Ouster proposed a new proprietary platform for crowd management and analytics designed for digital Lidar, Gemini[55]. Gemini is the provider of a new form of intelligence[56], critical in leveraging "the gold mine of value to be extracted from understanding people's movement and behavior". Crowd analytics, or "the art of understanding the flow of people in a particular setting", as demonstrated at the booth and later in the blog post reporting the activities at the fair, collects data through strategically placed sensors, outputs data analytics in the form of different kinds of visualizations or written records through dashboards or other kinds of screens, and allows the manipulation of the environment to be managed by optimizing zones that need more attention than others. Ouster proposes different kinds of analysis that can all be extracted from quantifiable behaviors in the relationship between moving object, duration, and location of movement.

[53] https://www.luminartech.com/technology last accessed 19/7/23.

[54] It's worth noting here how this technological bet realizes the globalist vision described in the 1946's short story by Luis Borges "On Exactitude in Science" (1946/1999), specifically upon the scale relationship between the territory to be represented and the map. Adding to that, a similar vision of replicating the globe has been put forward in the Minecraft community – see https://buildtheearth.net – in which a call for a shared project of recreating the whole world in scale 1:1 was published three years ago, and the project is still ongoing. On an academic note, the crowdsourcing of commercial vehicles to mine data to develop a real-time always up-to-date map looks like the perfect realization of the Infrastructural Surveillance (2020) theorized by Gekker and Hind, in which automated vehicles work as one of the main routes for capturing data from the environment and the users themselves, producing novel political assemblages as well as novel ontologies.

[55] https://ouster.com/blog/the-gemini-debut-at-ces-2023/ last accessed 18/7/23.

[56] Macrobius in the *Commentary to the Dream of Scipio*, Book 1, Chapter 21 (circa V sec/1990), provides the most ancient written justification, arrived to us, of Hellenistic Domiciles in ancient astrology. In the Thema Mundi, the natal chart of the world, Mercury, the planet associated with Hermes, and therefore representing Intelligence as well as a certain flair for tricks, given its commerce with the Underworld. It's curious that Ouster, a company dealing with data science, chose a name linked to what is nowadays considered a rather irrational side of cosmologic Western thought. A similar note appears in Wilmott's Mobile Mapping (2020, 199:226), in which she starts to explore Leibniz's Ars Combinatoria, considered, along with Descartes' thought, the origin of binary logic in its historical kinship with the I Ching.

These analyses are based, for instance, on the measurement of the capability of drawing the attention of potential "visitors", if the visitor is actually inclined towards a purchase, and finally on the level of engagement reached with the visitor. Before and after the detailed explanation of how and why Gemini, and the crowd analytics associated with it, can become central in optimizing commercial organization of spaces to invite more spending, the company highlights how Lidar is nonetheless the most important piece of technology in ensuring the safety of infrastructure. And indeed, in the proprietary site[57], this function of Lidar is heralded as a feature in smart infrastructure, to ensure the best performance in protecting key critical infrastructural sites. It's important to note how the commercial implications of crowd analytics will probably become central to the development of optimized strategies for advertising and managing flows of people within well-orchestrated spaces to ensure maximum profits. It's also important to note the presence of the idea of zoning, and the acquired idea that humans, once entering the zone, are to be considered as objects between other objects, with the special feature that their movement can only be strategically engineered and not forcibly directed. It's also interesting to note how once the crowd management system of data structure is in place, and the data is mined, even when the event of data collection terminates, the activity of extracting knowledge from crowd behavior doesn't cease.

[57] https://ouster.com/resources/smart-infrastructure-resources/security-lidar-solution-overview/ Last accessed 18/7/23.



Figure 139 Ouster's booth, screenshot of the photo on the mentioned webpage on new Gemini's functions. Previous videos I found about the booth have been taken down. Information on the website available in note 53.

To summarize, CES 2023 heralded an important step towards the explicit articulation of crowd surveillance in the development of Lidar sensing for driverless cars. In this ancillary function of Lidar, a key aspect is constituted by specific zones within the city that need to be optimized, for security, which still constitute a key component of the Lidar discourse, as well as a means of maximizing profits. As chronological time constitutes an important part of the spatial rationality visualized by Lidar, it's also important to note how temporalities emerge strongly as a way to produce new urban identities. In the following section of this chapter, I'm going to present how time and temporalities have been studied in Human Geography. The concept of flow will emerge as a defining articulation within the new biopolitics of security emerging from the technological landscape of remote sensing.

8.3 Of space-time matrixes and flows

As seen in the above section, time and temporalities constitute the backdrop of new articulations of knowledge and power. I will now discuss some important positions within the geographic study of time. I will then indicate the concept of flow as the central conceptual device that articulates crowd management. The concept of flow is not the only way to conceptualize time, as it emerges through the analysis of the data collected from this project.

A first available conceptualization of time is the discursive idea of velocity and speed, as I've touched upon in Chapter Five. A literature around acceleration is rich, but it would fall outside the boundaries chosen for the present study[58]. A second conceptualization of time is concerned with how time is materially intwined within the process of Lidar data production. A literature around real-time is rich and present[59].

[58] I've already referenced the work of sociologist Hartmut Rosa (2010), which presents an analytic framework to identify the causes and effects of the various speed-up processes that define modernity. The book develops a critical theory of late-modern temporality, which argues that acceleration ultimately leads to monstrous forms of alienation from time and space, from things and actions, and from self and others. Rosa sees acceleration as a distinctive condition of late modernity that is totalitarian in nature. The category of velocity is essential to the work of David Beer too (2018), as one of the distinctive features of the discourse around *data analytics.* Speed is also a core conceptualization in the critical work of Virilio (1977/2006) The book, a matrix for the whole later development of the author's work, presents a topological account of the entire history of humanity, focusing on the technological advances made possible through the militarization of society. Virilio argues that speed is the engine of destruction and presents a vision more radically political than that of any of his French contemporaries. He sees speed, not class or wealth, as the primary force shaping civilization. In this "technical vitalism," multiple projectiles, such as inert fortresses and bunkers, the "metabolic bodies" of soldiers, transport vessels, and now information and computer technology, are launched in a permanent assault on the world and on human nature. Similar positions are expressed by Lübbe (2009), while Torres (2016) analyzes the irrational foundations of the concept of speed, rooted in religion. Italian philosopher Franco Berardi (2011; 2017) has expressed several times apocalyptic views towards the rise of velocity in contemporary times, especially against those that argue for it (Williams and Srnicek, 2013), especially with the rise of AI (Brusseau, 2023; Hui, 2017).

[59] Robert Hullot-Kentor's "Metric of Rebarbarization" (2018) is a concept that refers to the process of dehumanization and barbarization that occurs when societies become increasingly reliant on real-time systems and technologies. Hullot-Kentor argues that the use of real-time systems is leading to a loss of human agency and a devaluation of human experience. He suggests that this process is a form of rebarbarization, in which the values and practices of a more primitive and barbaric past are being reintroduced into contemporary society. Marina Gržinić's "The Virtual-Image and the Real-Time Interval" (1999) is a paper that explores the changes in the space-time paradigm produced by cyberspace and virtual reality. Gržinić argues that all of our experiences of space and time are mediated by technology, and that the virtual image and the real-time interval are two key concepts that help us understand the relationship between technology and our experience of the world. The virtual image refers to the way in which technology creates a virtual representation of reality, while the real-time interval refers to the way in which technology mediates our experience of time. Gržinić's work has been influential in the fields of media studies and cultural theory, and has been the subject of much discussion and debate.
In the realm of geography, "The Real-Time City? Big Data and Smart Urbanism" (2014) is a paper by Rob Kitchin that explores the implications of big data and smart urbanism for cities. The paper argues that cities are being instrumented with digital devices and infrastructure that produce 'big data' that enable real-time analysis of city life, new modes of

However, as I explained in the previous chapter, a treatment of the digital materiality of time and the real-time streaming of data would lead me far from the data collected for this project. A third conception of time that arises from the dataset is that of *flow*. In this part of the chapter, I'm going to provide a reading of Time Geography and then I will focus on the idea of flow and how it highlights a pivotal consequence within the shifts in the hermeneutic relationship of the epistemic tool portrayed in the previous chapter.

Time has always constituted a difficult subject to grapple with. It can be considered one of the biggest enigmas in human life, as the myth of the Sphinx posits. Invisible, inconsistent, seems to always escape from the grasp of thought, both of common sense and of physics. And nonetheless, time constitutes the backdrop of every embodied experience, in its subjective quality, as well as the cage of days marked on the calendar, passing by with the cadence of an unstoppable cogged machine.

While the messiness of space has been bent to comprehensible units through the invention of the metric system, space keeps on been disciplined every day through the omnipresent use of digital mapping. Similarly, time has been divided into enumerable units, especially for economic reasons (Birth, 2022; Thompson, 1967). Nonetheless, the question of time still haunts spatial perspectives. Merriman (2012), for instance, challenges the notion of

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technocratic urban governance, and a re-imagining of cities. The paper details a number of projects that seek to produce a real-time analysis of the city and provides a critical reflection on the implications of big data and smart urbanism. The paper examines five emerging concerns: privacy, security, ethics, epistemology, and ontology. The paper concludes that while big data and smart urbanism offer many potential benefits, they also raise significant challenges and concerns that need to be addressed. The paper has been widely cited and discussed in the fields of urban studies, geography, and data science.

"Gender in Real Time: Power and Transience in a Visual Age" (2018) is a book by Kath Weston that explores the relationship between gender and temporality in the context of the visual age. The book argues that gender is a sociotemporal formation that is constantly changing and evolving in response to new technologies and cultural practices. Weston uses the tools of political economy, the history of science, and cultural studies to examine the ways in which gender exists in real time.

Much debate around temporalities was sparked by "Real Time Systems", a theory introduced by artist and art critic Jack Burnham in 1969 in an Artforum article bearing that title. Burnham's theory is a theoretic approach to art that focuses on the use of real-time systems to gather and process data from environments, in time to effect future events within those environments. Burnham argued that the proliferation of real-time systems was increasingly abstracting the concrete materiality of things into information. He contrasted this model with the traditional aesthetic notion of "ideal time", in which the contemplation of beauty occurs in theoretical isolation from social and temporal contingencies. Burnham's theory has been the subject of much literature and has influenced many contemporary artists.

space-time and even time-space, arguing against the attempt at crystallizing both of those dimensions, which has been a sort of obsession that has plagued many human geographers, from Harvey (1990) to Massey (1992; 1999)[60].

A similar position is heralded by Sarah Sharma in her book *In the Meantime* (2014). The book is an ethnographic-based exploration of several workers who negotiate their time and those of others, to work around established architectural temporalities. The arrays of workers interviewed by Sharma ranges from corporate personalities in airports, to taxi drivers, often having to challenge the temporalities of jammed cities to deliver them to fancy hotels or conference rooms. This array of different, and sometimes surprising, temporalities is described and analyzed by Sharma to deliver a theoretical counterpart to Massey's "power-geometry" (2012). Sharma too sustains that for far too long geography has been forgetting about the temporal dimensions, or, when confronted with the task to account for it, ended up reinforcing the space-time dualism. To counter-act this, she designs a "power-cronography", following the temporal biopolitics of experiencing different life rhythms within the city.

Everyday temporalities within urban life have also been analyzed by Crang (2001) in the attempt to describe the constellation of differences that can cluster in one space. His main goal is to give justice to the specific difference of lived experiences, without conceding to other-arching modernist generalizations that might inadvertently reinforce the idea of a Golden Age of unity with nature, an idea that could be striped by misogynistic or other discriminatory inclinations. The device used by Crang to describe the different rhythms composing the symphony of metropolitan life is Bakhtin's idea of the *chronotope*. In

[60] This position is also shared by Coeckelbergh (2020). In the post-phenomenology of technology, to my knowledge, reflection of temporalities are not abundant. Coeckelbergh proposes ways to consider technological relationships through the lens of embodied performance to consider temporal dimensions of unfolding, while also providing new visions of the technically mediated world.

literature theory, the chronotope is a conceptualization of the relationship between space and time within a text. Crang extends this idea to apply it to the reality of everyday life, with the ultimate goal of celebrating the unforeseeable nature arising from the crossing of subjective flows of experience[61].

Sutherland (2018) explores the history, ideology and social effects of mapping flows within the digitization of cartography[62]. He starts by not only recognizing the well-established fact that maps in general do not represent reality (Thrift, 1996), but also indicating that the main goal of his commentary is to explore the kind of world that flow maps *give* by tying together the collected numerical data and their representation. The visual representation of numerical data is given through a set of rules, following Galloway's study (2012). Sutherland convincingly argues that data visualization is the representation of the set of rules that allows for its conversion from the abstraction of the numbers towards their semiosis. As Parisi (2013) notes, algorithmic visual outputs are the effect of a logic of modeling, which is often heralded by flows. Flows of data, goods and people. Sutherland argues that flows are a metaphor signaling processes of representation

[61] This is not a complete literature around the concept of time in geography. Other important sources are listed below. Time and theory in human geography: Part II, by Nigel Thrift (1977), explores the relationship between time and theory in human geography, focusing on the ways in which different theoretical approaches have conceptualized time. *Time Geography* by Kajsa Ellegård (2018) provides an overview of time geography as a mode of thinking that helps us understand change processes in society, the wider context, and the ecological consequences of human actions. The book brings together international time-geographic research from a range of disciplines and situates the outlook for this developing branch of research and the application of time-geography to societal and academic contexts. *Time, Space, and Society: Geographical Societal Perspectives* by Aharon Kellerman (1989) explores the relationship between time, space, and society from a geographical perspective. Thrift and Pred (1981) presented an overview of time-geography as a new approach to studying the coordination of human activities in society and nature. The paper covered topics such as the basic concepts and notation system of the approach and the empirical studies that provide grounding for the time-geographical approach. In 2001, Martin Gren argued that time geography matters in human geography because it provides a way of understanding the temporal and spatial dimensions of human activity, while giving a list of other approaches to studying time and space, and the implications of time geography for urban planning and policy.

[62] This is a partial reconstruction of how the idea of flow sprang out in map-making. However, the most important conceptualization of the space of flows is provided by Castells (1997; 1991). Castells (2004) also provides an ethical rendition of the ontology of flows, how it is digitally structured through informational systems. Stalder (2001) reflects on the ontology provided by the logic of the flow through the financial market. Gross (2004) explores the relationship between human geography and ecological sociology, focusing on the flow of people and goods between different places. The article argues that understanding these flows is essential for understanding the social and ecological dynamics of different regions.

of time – specifically of movement – and proposes a history of the flow map as a formal instance of the spatialization of time, intensified by the development of GIS. To elucidate his point, he proposes a quick history of the flow map as a tool for acquiring power through the study of movement (Virilio, 2006). The starting point of this history of power-knowledge-movement is found in the design of the Tabula Peutingeriana, a table dated back to the Roman Empire, more a diagram of previously known itineraries through road networks, with Rome in the center, than a proper map in the modern sense. Still, Sutherland, following Talbert (2010), argues that it demonstrates the cartographic impulse of bringing back at a different scale and in two dimensions the networked complexity of movement through the world. Sutherland goes to explain how this proto-cartographic attempt at charting routes developed through the Exploration Age, aided by the development of new technical devices. The cartographic quest was also sustained by an "epistemological rationalization, essentially flattening out the spherical surface of the earth so as to fix it within a predetermined (Cartesian) geometrical schema" (Sutherland, 2018:178). Sutherland explains how these maps, however, couldn't register movement in the same way that applying flow charts to thematic mapping was able to do. Sutherland proposes illustrious antecedents, different in methodology and intended purposes, in the development of this branch of representing geographical information. He follows the study of MacEachren (1979), quoting the work of Henry Drury Harness, who, between 1836 and 1837, represented the flow of goods and people for the Irish Railway Commission. Another example is the infographic developed by Dr. John Snow, which maps the 1854 cholera outbreak in London, thus demonstrating its origin from a contaminated water pump, and defeating the miasmatic theory of contagion. The third example brought forth is the graphical rendition of Napoleon's defeat in Russia in 1812, produced by civil engineer Charles Joseph Minard in 1869. All these examples of maps managed to put on paper the subject to be represented, focusing on one specific theme and

defining it according to the quantities and qualities of its movement (origination, end, frequency, velocity, means of mobilization, volume). Quoting Harris (2000), Sutherland notes that through this formal apprehension and rendition of movement, anything can be represented through a flow map. He goes on to state that the metaphor of flow can be seen as a formal category that projects spatial qualities upon temporal dynamics. In this historical development, a great push for the notion of flow was granted by the advent of GIS, which

> Provide[s] the capacity for a form of mapping *premised upon flows* – in other words, of tracing the specific movements of various diverse objects, patterns and events (e.g. not only people, animals, raw materials and commodities, but also, information, capital and affect, etc.) over a specified period of time, centralising the once marginal figure of time within these practices. (Sutherland, 2018:186, original cursive).

This *a propri* constitution of Geographical Information Systems is also coupled with the fascinating outputs that they give birth to, distracting from the necessity of critically understanding the operations and effects they allow to develop[63].

And while the concept of *flow* has been deployed in the social sciences with different results (Bauman, 2000; Appadurai, 1996; Castells, 1991; 1999), the most important takeaway from Sutherland's exploration of the metaphor of flow and how it has been deployed in digital mapping practices is the idea that the map is not the product of an

[63] Sutherland quotes Monmonier (1993) and the adamantly enchanting feature of flow maps, which he explains with Virilio's (1994) indication of how fluid metaphors mimic the alluring freedom of the non-representational. He uses marine metaphors that I will explore elsewhere, as they are connected partly to my interviews, and partly to theoretical concept that I don't have the space to develop here, connected to the concept of orientation. However, I believe that the fascination with real-time representation of changing dynamic is connected to the idea of animation, as it has been developed in Animation Studies (see Buchan, 2013), but also in Cultural Studies through the ideas developed in the *Sex Appeal of the Inorganic* (Perniola, 2017), of a mutation and ongoing confusion between the animated and unanimated. Having the possibility to develop theoretical conclusions upon these matters, I would make a connection between Caillois' ideas (expressed in *L'Homme et le Sacré*, 1939/1950) about the uncanny spectrum and confusion arising from something unanimated imitating the movement of something animated. I would present as an example the fascination of the protagonist of *Der Sandmann* (Hoffman, 1817/2014) for Olympia, the mechanical puppet constructed by the protagonist and the character inspired by the Italian physics professor Spallanzani, in a complex plot of doppelgangers, which implies the importance of the then rising branch of optics and optical illusionism. I would then connect the fascination with optical illusionism with the French avant-guard artistic movement during 1920-1930, especially finding connections between Futurism plasticity and Riemannian geometries.

activity of representation. The map, as a layer of technical mediation, produces a representation of the world[64] and therefore of what can be and act in it. Following Stiegler (2011), flows and fluxes are the tools of the process of spatializing temporality in what can be called *grammatisation:* a way of rationalizing behaviors through protocols and producing distortion in the perception of time. Sutherland reports how, for De Landa (1991), flows can be seen as the result of the discovery of intricate and complex molecular structures within what once looked like pure chaos, thanks to the aid of the advancement of computational machines.

This idea of turbulence as chaos, and flow as finding a self-organizing order within the chaos, is also developed by Cubitt (1998) in his account of the development of communication networks across the globe from the telegraph, through the phone, to fiber optics. In his reconstruction, the first networked system in human history was the plumbing piping across cities: "a hidden and mechanical service directed towards the domestic user"(1998:129). The distribution system of electricity – and later of fiber optics – followed the secret patterns of water piping. In the beginning, electricity was described using fluid metaphors, as light streamed through the streets of the city and substituted, through the diffusion of home appliances, the primacy of water as a source of hygiene.

[64] It's interesting to note here how Sutherland is deploying post-phenomenological ideas without reproducing the post-phenomenological schema or using the terminology, but actively deducing them purely from the genealogy of cartographic interventions in the development of flow maps. I believe that the only difference between this approach and the post-phenomenology of techno-science can be found in the attention given to the epistemic tool. My interest for the epistemic tool of Lidar sensor and how it is interlaced with time was sparked by one of my in-depth interviews with a perception engineer who has been in the market since the end of the 80's. Compared to the other interviews I had, with younger personnel, he demonstrated a much deeper understanding of spatial problems and how they relate to human geography. He suggested to me the difference between the first attempt at GIS, trying to reproduce the world through polygons vs. modeling the world through Lidar. He could point towards these nuances, having developed the informatic part of GIS systems since the 90's, and having experienced first-hand the evolution of the technoscience around it. He told me that he viewed the work of the engineer as parallel to the activity of the British Explorers: trying to conquer the big unknown. In this sense, he added, he was way less interested in the development of Lidar for driverless cars and more in "weird" (his term) applications in outer space explorations. He also strongly underscored how Lidar sensing is intrinsically connected to the ability to measure time (i.e. Time of Flight), and drew once again a parallel between current engineering work and the design and crafting of the first chronometer by a lone watchmaker, John Harrison, who, in the XVIII century, provided a "technoscientific" answer to the unsolved problem of defining geographical longitude (Sobel, 1995). A similar material account of cartographic endeavor can be found in Turnbull's reconstruction of the design of La Carte de Cassini, also in the XVIII century (Turnbull, 2000).

The fluid metaphor, and productivity, of electricity was largely subdued with the invention of the wall socket (Schroeder, 1991). Standardization disconnected the semantic ties between electricity and its material, interconnected, distribution system. Nonetheless, the mechanical model of water, borrowed from electricity, went on shaping information theory, especially through the work of Claude Shannon, later popularized by the writing of Wiener (1948/2019), today still considered the father of cybernetics. Shannon resolved the problem of information loops overcrowding telephone lines. Information loops needed to be severed in their circulation, thus making it flow only in one direction, from input to output and so on. Taming turbulence, conceptually and materially, allowed for the surveillance of information flows.

"The management of flux, deformation and density of crowds" (Nishiyama, 2018:4) constitutes the chore of a "rheological"[65] mechanism at the core of the new declension of the biopolitics of security, especially within the urban site. Nishiyama's analysis stems from the acknowledgement of the introduction of surveillance technology connected to crowd behavior analysis by NEC Corporation, in a specific zone in Tokyo, in 2015.

In contrast to traditional surveillance technologies that detect and follow individuals, crowd behavior analysis technology focuses on crowds as an object of monitoring and is designed to understand their movements. It also makes the behavior of crowds, like other recent digital technologies such as computerized biometric systems, machine-readable. By rendering crowds machine-readable, the technology enables the automatic detection of potential incidents and dangers in the urban environment. (2018:3).

[65] The connection to rheology, the branch of physics that studies the deformation and flow of matter, is also evoked by Turk (2018) as a critical call for avoiding stopping the change in studying dynamic maps. The author shows the methodology by analyzing humanitarian maps through Sloterdijk's concepts of bubble and foam (2011). This methodology has also been deployed by Klauser (2016) in his analysis of the co-production of space and surveillance.

To perform its function, crowd monitoring relies on dividing the image and projecting onto it a grid that creates zones. These zones are independently analyzed and compared to simulations, in order to find patterns of behavior that are considered normal according to a pre-determined sample that has been computationally elaborated. Abnormalities within what has been coded as normal are obviously detected by tracking every unit composing the group monitored, in order to find deviating behaviors, according to density and flow as the main parameters. Nishiyama alerts about how the management of crowds' flow within the urban site signals a change in the biopolitics of security. The object of the biopolitics of security is either the individual or the population. The individual is usually examined and taxonomized, looking for adherence to a norm, while bodies that do not conform are either expelled or contained (Foucault, 1975). These measures are taken in order to preserve the life of the population (Foucault, 2003) and actually allow it to prosper in the socio-economic system. According to Nishiyama, the target of crowd surveillance is the *body of urban life,* nor individual, nor national population. The urban crowd exists only within a specific urban space-time matrix. Crowd management inherits the politics of suspicion typical of border control (Adey, 2009; Amoore, 2006; Epstein 2007) and combines it with pre-emptive action (Andrejevic, 2017; Massumi, 2007), while producing the idea of the identity of the crowd as something dangerous that needs to be monitored[66]. In doing so, crowd surveillance disciplines, as it constructs a pattern of movement as normal, comparing it against a set of knowledges already available through computing.
But it also preserves the life of the population, monitoring the behavior of the crowds and promising intervention if anomalies were to arise, or even before. Crowd surveillance is also sold as a-racial, ignoring individual features while sampling the quantitative qualities

[66] Crowds have a history of being considered irrational and uncontrollable in police enforcement manuals (Gargiulo, 2022). This development seems to be an intensification and systematization supported by the technological encoding of ideas and practices that were already present in the public order discourse.

of crowds. It seems to respect privacy and avoid racialized targeting. Nonetheless, Nishiyama notes how it can criminalize certain behaviors, or might inherit biases through datasets used to train algorithms. Moreover, focusing attention on specific areas of a city might show a correlation with migration practices. Adding to that, the logic of suspicion is correlated with racially coded practices around who might be a threat, a legacy of the war on terror. Nishiyama concludes by highlighting how once crowd management was reserved for border control and it's now spreading to the surveillance of mega-events as well as specific areas within cities.

Nishiyama's characterization of the biopolitics of (in)securitization of the crowd as a rheology is confirmed by the fact that data scientists have been modeling the behavior of groups through algorithms "through the lens of hydrodynamics" (Moore et al.; 2011) for at least a decade (Arbab-Zavar and Sabeur, 2020; Chiappino et al., 2015; Sabeur and Abab-Zavar, 2022; Zhang et al. 2018).

8.4 Conclusion

In this chapter, I describe a remarked shift from the concept of mobility towards the notion of *surveilling* mobility, in the development of Lidar sensing for driverless cars. With this shift, the liquid-like flocks of humans that cross specific areas of the smartly enhanced city become the new identity of a biopolitics of security. The streaming group of people to be measured is not individual but does not even correspond to a population. The claims for privacy, and therefore the legitimate benevolence of this kind of way to "measure people", do not consider how technological biases are already inscribed in the logic of suspicion guiding their development and deployment. As this technology is still not commonly used within urban landscapes, the risks embedded in the emergent

articulation of bio and necropolitics are mostly speculative. This speculation is nonetheless based on materials being published by relevant companies, and in this respect, it's also raising a distinction between what's written on the sites and what's showed at technological fairs. Moreover, the notion of flow of data also alters the computational process of modeling the environment, producing new regimes of visuality and in the articulation of hermeneutic relationships technologically mediated. I will now compare two positions from media studies and contrast it with a post-phenomenological consideration, to conclude.

A conception of flows is expressed by Gaboury in his book *Image Objects* (2021). In this archaeology of computer graphics, the author traces back the development of reproducing images of objects through algorithmic processes in the progressive development of hardware and software, from the 60's to the rise of CGI. Computer graphics, in this account, is described as the process of replicating objects by tracing polygons that need to be fixed on a computational grid through a set of coordinates. In order to reach realism, a subtractive logic was essential: things that were not in sight in real life needed to be copied in their structure and then edited to mimic real life obstruction of sight. In time, memory and graphic processing units were invented, making the design of more complex shapes easier, as set of coordinates and computational processes could be stored and retrieved. Gaboury's archaeology attempts to explicate, through the story of the engineers and their technical invention to solve tasks, the ontological question of a world made of objects that exist and are stored in computers, as an image, that is also a computational object itself. This world of doubles is governed by an inner logic:

> Unlike those media that defined the episteme of the twentieth century, in which history is preserved through the acts of recording the passage of time, graphical hardware does not preserve history; it hardens it into a singular logic that executes the act of representation.

> Yet this historical thing it crystallizes is not change or transformation but rather the logic of procedural flows, of repetition and acceleration, a procedure crystallized. (2021:187).

As we have seen, however, Lidar imaging doesn't work on the basis of computer graphics. Objects, among which are counted human bodies too, are not replicated mimicking the geometry of the shapes that compose them. Objects are modeled by extracting a series of points measuring the time that a photon spends while traveling from the laser emitter to the surface that needs to be sensed. I turn to another media scholar, who based his work upon Farocki's ideas, already touched upon in Chapter Four.

Parikka's book *Operational Images* (2023) analyzes machine learning and its specific mode of vision, through a rich series of case studies, concluding that the visualizations of data extracted through remote sensing, because of their military origin, are important not for what they represent but for the kind of operations that they allow. In this sense, they are to be considered as aesthetic-operative devices. This means that they do something and allow something to be done, promoting an evolution towards an "invisual culture". This term is borrowed by MacKenzie and Munster (2019) who, explicitly citing Lidar technology, consider machine learning as a "making operative of the visual by platform themselves" (2019:6). Parikka has an entire chapter about how Lidar imaging, within the development of driverless cars in the urban landscape, will be the key to the transformation of the city into a post-lenticular site, completely devoted to the logistical flow of goods, people, information.

Lidar sensors are intertwined with flows at an epistemic level. The idea of the flow is coded in the grammar of hardware and software composing the perceptual stack of Lidar. The epistemic tool produces a hermeneutic reading of the world as a space crossed by temporally determined flows. Indeed the notion of flow, inherent in the physical and

conceptual processes applied to both humans and objects navigating a space-time matrix – delineated by the region designated for Lidar data extraction – position them as performers guided by implicit rules, as they are caressed by photons that generate a set of spatial relationship to be subsequently compared against a predetermined, encoded, standard.

Some of these flows traversing space/time, transduced as coded space and determined by a set of mute and everchanging rules, happen to be constituted by humans and, in a strange unsolvable permutation between individual and collective, it appears that Wellner's thesis (2017), according to which humans are becoming the substrata of algorithmic writing, thereby inverting the hermeneutic relationship between human-technology-world as it has been previously discussed, might indeed be in effect.

Chapter Nine

Conclusion
Of Mirrored Gazes

"Then the one who ran away must be Leibniz?" Wang asked.
"Indeed, an unscrupulous man. I don't really care about this little claim to fame. Inventing the three laws of mechanics has already made me the greatest, God excepted. From planetary motion to cell division, everything follows the three great laws. Now, with the powerful mathematical tool that is calculus, it will only be a matter of time before we master the pattern of the motion of the three suns."
"It's not that simple," said the man who had tried to stop the fight. "Have you considered the amount of calculation that's needed? I saw the differential equations you listed, and I don't think an analytical solution is possible, only a numerical one. However, the calculating capacity required is such that even if all of the world's mathematicians worked without pause, they'd still not be able to complete them by the time the world ended. Of course, if we can't figure out the pattern of the suns' movements soon, the end of the world will not be too far away." He bowed at Wang as well, a more modern bow. "Von Neumann."
"Didn't you bring us thousands of miles to the East specifically to solve the problem of calculating these equations?" Newton asked. Then he turned to Wang. "Norbert Wiener and that degenerate who just ran away also came with us. We encountered some pirates near Madagascar. Wiener fought the pirates by himself so that the rest of us could escape, and he died valiantly."
"Why did you have to come to the East to build a computer?" Wang asked Von Neumann.

Von Neumann and Newton looked at each other, puzzled. "A computer? A computing machine! Such a thing exists?"
"You don't know about computers? Then what did you have in mind for completing the vast amount of calculations?"
Von Neumann stared at Wang with wide-open eyes, as though his question made no sense. "Using people, of course. Other than people, what else in the world is capable of performing calculations?"
"But you just said that all the mathematicians in the world wouldn't be enough."
"Instead of mathematicians, we'll use common laborers. But we need many of them, at least thirty million. We'll do mathematics using human wave tactics."
"Common laborers? Thirty million?"
Cixin Liu, *The Three Body Problem*

…qui contra spem in spem credidit, ut fieret pater multarum gentium, secundum quod dictum est: "Sic erit semen tuum".
Saint Paul, *Letter to the Romans, 4,18*

9.1 Introduction

The primary goal of this study is to elucidate a critical geospatial understanding concerning the emergence of geovisualities, exemplified by augmented maps produced through Lidar sensor technology employed in autonomous vehicle development.

Lidar-generated images possess distinctive aesthetic and functional attributes that engender a complex interplay between spatial and visual dimensions. Moreover, despite their ethereal appearance, these images project scientific objectivity. The sensor operates in a manner that seemingly replicates objects within its mechanical purview as impeccable digital doppelgängers. This illusion of perfection often leads to the assumption that algorithmic processes effortlessly yield a neutral representation of reality.

The deconstruction of this ostensibly neutral facade aims to contribute to an analysis of the imaginary, serving as the horizon of possibility and intelligibility in the development of augmented mapping techniques. This critical effort corresponds to the need for new philosophical approaches to cartography in the digital era, as discussed by Perkins (2003:342), particularly emphasizing the role of remote sensing (Bennet et al., 2022). As fleets of automated systems threaten to permeate urban landscapes, meticulously

scrutinizing every nook and cranny through photonic surveillance, it becomes increasingly crucial to examine the implications of such technological interventions.

This overarching goal rekindles the need for engagement with age-old cartographic enigmas. These enigmas assume paradoxical dimensions when situated within the rapid, dialectical succession of technological innovations and unforeseen lapses.

9.2 The algorithmic imaginary of Lidar imaging

Within the framework of this research, the response to the call for a renewed examination of digital technologies from a geospatial perspective has been formulated through a detailed analysis focused on addressing three specific questions, underpinned by the collection of concrete empirical evidence.

The study's objectives encompass the delineation, encoding, and decoding of the commercial discourse shaped and reinforced by Lidar imaging. Furthermore, it seeks to scrutinize the relationship between data acquisition and visual representation. Additionally, it endeavors to articulate the spatial and temporal dimensions engendered by Lidar imaging and its deployment.

In pursuit of these objectives, the research draws upon three foundational bodies of literature. Firstly, it engages with Critical Geography, which engages with geo-visual representations to examine how they are created, used, shared and interpreted, with attention to social and ethical implications. Secondly, it delves into Critical Data Studies, concerned with the reconstruction of how data operate within the realm of hardware and

software. Lastly, it aligns with Surveillance Studies, which are dedicated to the politics of observation and their ensuing political ramifications.

To address these inquiries, the empirical chapters are organized as follows. The initial two chapters contextualize and analyze Lidar imaging within the broader cartographic tradition. The third chapter employs film theory as a conceptual framework to reconfigure the spatial representations conveyed through Lidar imaging, serving as a critical inflection point. The fourth chapter explores the digital materiality of Lidar imaging, to unveil the epistemological underpinnings supporting it. Finally, the last empirical chapter introduces an evolution in the biopolitics of surveillance, centered around the spatio-temporal concept of "the flow".

Chapter Four comprises an essential analytical core, based on an online survey of businesses engaged in Lidar production for autonomous vehicles, accessible through their websites. These businesses frequently employ visual marketing strategies to establish themselves as industry leaders in technology, attracting investors and fostering collaborations. Distinguished from conventional digital mapping tools by their origins in specialized engineering software, these images, often referred to as 3D or HD maps, deviate from traditional cartography in both appearance and function. They hold significant importance in shaping brand identities and marketing strategies, given their unique visual and functional attributes.

This chapter serves a dual purpose: firstly, to archive Lidar imaging as it appears on corporate websites, and secondly, to meticulously examine these images in order to gain a deeper understanding of their deployment. The primary objective is to scrutinize the discourse emanating from Lidar imaging, both in its production and reproduction. This

analysis provides the first step in the process of reverse-engineering the data collection process and the subsequent construction of spatial and temporal representations. Through this methodological approach, and within the scopes set forth by the research questions, we can gain insights into the roles played by both hardware and software in the creation of data visualizations.

Within the broader context of the datafication of urban life, this chapter zeroes in on Lidar companies, positioning Lidar imaging as a medium for crafting spatial representations. These visual depictions are considered through the lens of persuasive geographic imaging techniques. The study illuminates the profound significance of Lidar imaging in the realm of branding and its far-reaching implications. Furthermore, it identifies historical instances of promotional mapping, with a particular focus on maps promoting various infrastructure projects, such as highways, air travel routes, and telecommunications networks. Particular attention is paid to how ostensibly neutral infrastructural changes can give rise to unintended racial consequences.

The findings gleaned from the survey illuminate a noteworthy trend: Lidar point clouds are prominently featured in marketing strategies, primarily for their aesthetic allure, which I called “auratic”, rather than for purely scientific or informational purposes.
Lidar imaging is conspicuously set apart by its aesthetic appeal, forming a connection with futuristic concepts and bolstering what can be termed as "cyberboosterism" (Dodge and Kitchin, 2000). Brands employ these visuals to project a diverse array of possible automated environments, while showcasing images of future vehicles. The intended arena of deployment is notably the urban landscape, where the concept of smart cities takes center stage. However, given the inherent volatility and turnover within the industry, the realization of a fully automated urban landscape remains ambiguous at best. Economic

downturns have ushered in a shift towards the development of Advanced Driver Assistant Systems (ADAS) for electric vehicles, a strategic response to the challenges encountered by established players in the field.

Chapter Five moves deeper into the argument advanced in the preceding chapter, undertaking an analysis of the commercial imaginaries that underpin Lidar companies. These imaginaries, in turn, exert influence over how Lidar imaging is perceived, employed, and the purposes it serves.

The chapter commences with an exploration of a keynote address delivered in 2019 by a prominent figure in the tech industry at MIT. The speech emphatically emphasizes the imperative of advancements in automation to prevent loss of life. The backdrop of this speech, visually featuring a stark counter of real-time death, introduces a necropolitical undertone to the fervent discourse, echoing the racialized schisms briefly touched upon in the preceding chapter.

However, prior to decoding the significance of the multimodal representations of Lidar found on corporate websites, the chapter provides a concise overview of the intricate entanglements between the development of driverless vehicles and broader concepts such as smart urbanism, platform urbanism, living labs, and the attendant concerns regarding privacy within these technological ecosystems. This contextual framework serves to establish the research's background, while underscoring its significance within the domain of human geography.

Nevertheless, the primary focal point remains the construction of perceptual systems based on laser technology, examining the contingent primacy these technologies have assumed in the making of autonomous vehicles.

The sample to be analyzed encompasses eight companies, all of which strategically employ visual tactics on their websites to bolster their branding efforts. These strategies harness a combination of eight distinct categories—safety, time, performance, vision, intelligence, universality, and revolution—interwoven within displays of point clouds or simulation videos. Seven of these companies leveraged point clouds to accentuate the strength of their claims about their products, with variations in prominence, following a hierarchical schema. Point clouds were presented in various multimedia formats and supplemented with textual or verbal aids to convey intended meanings.

Among the surveyed companies, Luminar and Ouster placed significant emphasis on visual branding, devoting substantial homepage screen space to meticulously crafted interpolated point clouds, for maximal aesthetic impact. In contrast, AEye exhibited minimal point cloud content, while Pony.ai opted to forego point clouds, instead prioritizing the end user's perspective of the vehicle's interaction with the surrounding environment. Nevertheless, Pony.ai did provide a succinct discourse on the role of Lidar imaging in the development of driverless vehicles in an explanatory video.

The discourse encompassing Lidar's function often oversimplifies its role within the broader perception suite. It is frequently depicted as the primary sensor within a composite array comprising cameras, radar, and GPS, collectively facilitating real-time mapping. The data collected undergoes fusion through a Kalman filter and subsequent processing via machine learning software, enabling semantic segmentation to identify

objects such as vehicles, bicycles, landmarks, and pedestrians. This, in essence, forms the foundational control system governing the vehicle's decision-making in response to encountered obstacles.

The companies showcased a diverse array of urban landscapes, encompassing iconic landmarks, bustling streets, highways, intersections, and parking lots. Cinematic compositions frequently featured suburban landscapes, portraying a more leisurely pace of life and the ever-moving landscapes observed through vehicle windows.

By strategically weaving together the identified categories, these companies strive to position their products as revolutionary and disruptive, while also being safe and secure at the same time. They construct distinct spatial narratives through digital perception, intimately linked with temporal dimensions that underscore velocity and swiftness, thereby projecting compelling visions of the future of urban dwelling.

Chapter Six places the moving map at its focal point. After invoking Crary's seminal exploration of optical toys as an illustrative precursor to the analysis (1992), attention is directed towards the materials that significantly contribute to the cybernetic allure of Lidar imaging—the ceaseless flux of minuscule points scattered across a black canvas, faithfully mimicking the surrounding environment.

Before embarking on the in-depth analysis of the videos, an introductory historical perspective is offered, drawing inspiration from feminist theorist Mulvey (2006) and cinema semiotic theorist Bertetto (2010). This historical interlude traces the intersection of geospatial representation and movie animation, where cartography later converges with computer graphics. The journey encompasses the period from World War II to the

renowned Aspen moving map, seen as an epistemic tool preceding augmented mapping. This concise and fragmented historical account serves to underscore the fleeting contingencies both within and beyond academic circles that brought the cognitive potential of moving images conveying geographical information to the military's attention. It is this very cognitive potency of the epistemic tool that now emanates from the captivating and disquieting aesthetic appeal embodied by Lidar imaging's dancing neon-colored stars.

Transitioning to Lidar videos, the chapter invokes concepts from film theory, such as the image's spatial significance, spectatorship dynamics, color palettes, point of view, and temporal elements. Lidar imaging unveils intricate notions of subjectification and objectification, often imbued with elements of magical thought and anthropomorphism. Data visualization effectually shifts the focus from physical objects to the surfaces intercepted by photons. The utilization of software-driven segmentation and curation results in the creation of hieratic surface models, revealing the sensor's capabilities extending beyond Euclidean geometry and the limitations of the fixed human perspective.

Lidar's enigmatic essence arises from its technoscientific origins, designed for navigation and apt to the generation of a digital realm distinct from human exploration, in contrast to domains like cinema or art. The challenge in digital mapping lies in the animation of surfaces, endowing them with temporal luminosity, and navigating within defined geospatial boundaries. The screen serves as an intermediary interface between divergent spatial logics—the spherical and the planar—resulting in the emergence of meta-connections.

Ultimately, the analysis confronts the intricate complexities of Lidar imaging and its presentation by companies, acknowledging the inherent tension between surface representation, light manipulation, and the underlying spatial logics that cooperate toward the construction of visualizations.

The companies subjected to analysis in the fifth chapter exhibit a common tendency to eschew detailed descriptions of the intricate mechanisms underpinning their sensors, particularly concerning data capture and processing. On their proprietary websites, Lidar videos emerge as the preferred visual strategy, depicting a flurry of colored dots in animated patterns against the video backdrop[67]. These captivating videos conjure phantasmagorical cityscapes or present intricate three-dimensional renderings of the autonomous vehicle and its surrounding environment. This visually compelling strategy exhibits remarkable consistency across a diverse array of companies and is disseminated through both physical and digital platforms.

[67] The output format of Lidar data can vary depending on how it's processed and what specific information is extracted from it. Lidar data itself consists of point-cloud data, where each point represents a 3D coordinate (X, Y, Z) along with additional attributes such as intensity or classification. However, when it comes to visualizing or representing Lidar data, it can be converted into different formats including vector and raster (bitmap) formats. In the first case, Lidar points are typically represented as individual vector features with attributes attached to them. Vector formats are useful for maintaining precise geometric representations and storing attributes associated with each point. But Lidar data can also be converted into raster formats. In this format, Lidar points are converted into a regular grid of cells, where each cell represents a specific area on the ground and contains information such as elevation or intensity. Raster formats are commonly used for visualization and analysis in Geographic Information Systems (GIS) and remote sensing applications. Lidar outputs depend on how the data is processed and what specific format it is converted into for visualization or analysis purposes, depending on the requirements of the application (Rottensteiner and Briese, 2003; Shi et al., 2011).
Lidar data, like many other forms of spatial data, is often visualized on a screen using pixels. However, it's important to distinguish between the representation of the data for visualization purposes and the nature of the data itself.
When Lidar data is visualized on a screen, it's typically converted into a raster format, such as a Digital Elevation Model (DEM) or an intensity image, where each pixel represents a value derived from the Lidar points within a certain area.
In this context, the Lidar points are not directly represented as pixels; rather, the data is converted into a pixel-based representation for visualization. This conversion involves various processing steps, such as interpolation, resampling, or aggregation, depending on the specific visualization technique and the desired output.
On the other hand, voxels are three-dimensional pixels that represent volume elements in a grid-based data structure. Voxels are commonly used in medical imaging, computer graphics, and other fields to represent volumetric data. While Lidar data can be used to create voxel grids for certain applications, such as 3D reconstruction or terrain modeling, the raw Lidar points themselves are not voxels. They represent precise points in space rather than volumetric elements.

The discourse enveloping Lidar technology extends across a spectrum encompassing informative websites, blogs, conferences, and educational materials. A common thread running through this discourse is the resounding emphasis on Lidar's pivotal role in shaping the future city. Lidar is depicted as a transformative technology capable of universally disseminating real-time data capture, automated intelligence, and precise mapping. Within this discourse, the primacy of safety emerges as a paramount consideration, not only in the development of intelligent urban infrastructure but also in domains such as pattern recognition, crowd management, and safeguarding critical sites.

The pervasive uniformity of this discourse raises salient questions regarding Lidar's historical positioning within the realm of cartography, alongside its embedded power structures and knowledge paradigms. To approach Lidar mapping with a critical lens, a multidisciplinary approach grounded in film theory is invoked, drawing inspiration from the exploratory endeavors of critical geographers of Geographic Information Systems (GIS). This interdisciplinary approach seeks to unearth insights that extend beyond the confines of conventional discourse. The choice of film theory as an analytical framework finds resonance in Lidar's presentation in media, catering to both expert and lay audiences alike.

The application of film theory offers an illuminating perspective on the intricate complexities of Lidar technology, delving into its synergies with the domains of cinema and defense research. This interdisciplinary approach is substantiated by the material evolution of the sensor itself, providing insights into its operational mechanics and far-reaching implications.

Subsequently, in the following chapter, I embarked on a comprehensive exploration of the historical trajectory of Lidar technology, spanning from its inception to its contemporary manifestations. This reconstruction aims to traverse the landscape of evolving ideas, materials, convergences, schisms, and iterative experimentations that collectively have imparted shape to the making of this tool. The genealogical expedition unearthed Lidar's intriguing connections with seemingly disparate realms such as searchlights, cinema, spectacle, and telecommunications. Furthermore, I recounted the investigation of the intricate hermeneutic interplay that binds together humans, epistemic tools, and the world. The aim of this chapter was to unravel the foundational and phenomenological facets afforded by the Lidar experience, transcending the protective discourse that currently envelopes it at a commercial level.

In the pursuit of these objectives, a granular examination was undertaken to elucidate the material foundations that underlie Lidar's digital spatial management capabilities. While the examination did not extend to the contemporary software layer, because of industrial secrecy, it traced the lineage of spatial algorithms, leading the exploration back to wartime and military antecedents. The knowledge and power encapsulated within Lidar technology were not transmitted through a malevolent lens; rather, they were apprehended as an automated consequence stemming from obligatory technoscientific gestures. These gestures, emblematic of human-technology interactions, are fortified by the space-managing metaphor of the grid, strategically deployed to guard against the uncharted, the unknown, the uncertain.

At its essence, the process of scanning and modeling space, when seamlessly synthesized in the digital realm for visualization, aspires to purify space from irregular occurrences. This operational imperative is not merely a byproduct of technique or

technology; rather, it emerges as a manifestation of the automated aesthetics embedded within the connections of materials, relationships, and processes. This represents an attempt to bring order to the perceptible world and to demarcate the horizon of possibilities where actions can unfold.

In the culminating chapter of this empirical investigation, the focus pivots from the interplay of Lidar's digital materiality with spatial representations and its implicit temporal correlations, shifting toward the temporal dimension of Lidar sensing. This transition takes place within the broader context of the dance between observation and being observed, as illuminated through the prism of Surveillance Studies in the second chapter.

The nexus between temporal aspects and the surveillance apparatus is probed through the insights gleaned from Vukov's essay (2016). Vukov's work dissects the realm of digital surveillance, particularly its impact on racially marginalized communities. Vukov challenges the notion of a post-racial world, asserting that when tethered to surveillance practices, such claims falter. This argument is substantiated through a compelling case study involving the smart border that separates Canada and the United States. Despite declarations of race-blindness, the technologies deployed at border crossings encode racialized practices. Borders, both physical and conceptual, serve as potent symbols of the divide between population inclusion and exclusion, and the contours of racializing practices extend beyond mere geographical demarcations.

Vukov astutely identifies algorithmic profiling as a linchpin within border practices, facilitating real-time prevention and intervention. The discourse traverses four categories of technologies instrumental in reshaping the dynamics of race through data collection

and the inscription of specific targets: bioembodied inscription, movement sensing and geolocation, autonomous machinic technologies, and algorithmic data assembling and storage. These technologies collectively contribute to the reconfiguration of race within the ambit of bordering practices.

Within this chapter, I expound upon a consequential transformation in the conceptualization of mobility, particularly the shift from the mere act of physical movement to the surveillance of mobility within the context of Lidar sensing for driverless cars. This paradigm shift underscores a pronounced biopolitical focus on security, encapsulating not only the movement of individuals within smart cities but transcending individualization. Privacy concerns, while undeniably pertinent, often fail to fully appreciate the intrinsic technological biases enmeshed within the development and deployment of such systems. Although the potential risks entailed by the convergence of Lidar technology with bio and necropolitics remain largely speculative, due to its current limited utilization, compelling evidence gleaned from the publications of relevant companies informs these conjectures. The notion of data flow emerges as a critical underpinning, reshaping the computational processes entailed in environmental modeling and ushering in novel visual regimes and hermeneutic relationships.

It is critical to acknowledge how Lidar sensing resides at the heart of this epistemic flows meant to cross space and time. This notion of flow is imprinted within the very hardware and software constituting the perceptual stack of Lidar, thereby engendering a hermeneutic interpretation of the world as a space fundamentally characterized by temporally orchestrated flows. This perspective introduces the possibility that humans are evolving into the substratum of algorithmic authorship, heralding a transformation in the traditional relationship that binds together humans, technology, and the world.

9.3 Academic Contribution

To respond to research questions, Lidar imaging prominently occupies the digital domains of the companies engaged in its development and commercialization. Lidar imaging assumes a central role online, orchestrated to sustain a discourse that elevates Lidar to a position of paramount importance in the envisioned progression toward urban autonomy. This trajectory aspires to usher in a reimagined city, one that is resoundingly smart, exceptionally efficient, extraordinarily rapid, universally standardized, meticulously optimized, and, above all, unequivocally secure. In the context of the development of driverless cars, the notion of security is especially bound to the imperative of mitigating fatal accidents between vehicles and pedestrians. However, in the backdrop of recent economic downturns, Lidar technology has increasingly gravitated toward crowd management—a development seemingly encoded within the intrinsic grammar of the materials comprising the optical and digital components of the sensor. This trajectory, historically motivated by a desire to transform turbulence into orderly flow, appears to inadvertently cast humans as the raw material subjected to the inscription and interpretation of software.

This study's foremost merit lies in its resuscitation of a set of geographical techniques hitherto consigned solely to the realm of engineering, ushering them back into the purview of critical cartography. It serves as a demonstrative testament to the necessity for critical geography to engage fruitfully with Lidar imaging, and remote sensing more broadly, necessitating a fresh confrontation with largely forgotten mapping lineages. This entails a deliberate reexamination of their seemingly incidental encounters with artists,

engineers, and laboratories to foster epistemic tools beyond the Cartesian residues highlighted in the seventh chapter.

The second original contribution of this study is to the domain of Critical Data Studies, and rests in its utilization of concepts commonly associated with the field of Human-Machine Interface. These concepts are adroitly employed to unravel the digital syntax permeating the entirety of Lidar imaging's stack, encompassing both software and hardware components, thus integrating a holistic perspective.

Furthermore, through the amalgamation of time geography with a distinct facet of Surveillance Studies, this research rekindles the call for novel articulations concerning the biopolitics of surveillance. It sensitively navigates the emergence of ephemeral categories that defy conventional classification, eluding both collective and individual categorization.

9.4 Limitations and future perspectives

However, it is imperative to acknowledge the inherent limitations of the present study. Notably, it represents a partial exploration of the terrain encompassing Lidar imaging, with numerous uncharted branches of inquiry left unexplored in the interest of maintaining coherence. Additionally, a crucial point to underscore is the unmistakable Western-centric orientation characterizing both the materials analyzed and the ensuing analysis.

While I must acknowledge the limitations of my study, which mainly revolve around the necessity of defining boundaries for a topic that could span various disciplines, and the

constraints of my own background that led to a focus on the Anglo-Saxon world, I want to emphasize how an experimental technoscientific agenda could greatly benefit from the involvement of researchers from diverse fields and geographical areas. Such interdisciplinary collaboration could help identify and compare global differences and similarities in the context of this emerging field. A commendable example of this approach can be found in Benjamin et al.'s (2021) study, which highlights the intrinsic uncertainty in machine learning applications and underscores the importance of explicitly articulating and incorporating this uncertainty into design practices. The uncertainty embedded in technoscientific tools and their usage has a profound impact on how humans perceive and engage with the world, both in spatial and temporal dimensions.

On a theoretical level, my work also has its limitations. As should be evident by now, Lidar imaging serves as an emblem for visualizing technoscientific tools that challenge established semiotic relationships within and beyond the field of geography. Lidar imaging calls for a deeper exploration of the philosophical conceptions inscribed in technoscience through the materials and principles of its operations. This work challenges the prevailing epistemology of functionality, which underpins today's scientific practices. However, as demonstrated in my final empirical chapter, Lidar imaging represents a pivotal moment at the threshold of redefining the distinction between natural and artificial organisms. It also raises questions about how this technology is applied to design atmospheric boundaries within urban environments, where entities can undergo shifts in their ontological status.

This thesis encourages further exploration of the material presented, spanning across various disciplines and geographic regions. It also invites profound investigations into the

historical and theoretical evolution of the technology, with the aim of demystifying its veiled workings.

Bibliography

Aberbach, J. and Rockman, B. 2002. Conducting and Coding Elite Interviews. *PS*: *Political Science & Politics*, 35(4).

Adey, P. 2009. Facing airport security: Affect, biopolitics, and the preemptive securitisation of the mobile body. *Environment and Planning D: Society and Space*, *27*(2).

Agostinho, D. 2018. "Chroma Key Dreams: Algorithmic Visibility, Fleshy Images and Scenes of Recognition" in *Philosophy of Photography* 9 (2).

Agostinho, D. 2019. "The Optical Unconscious of Big Data: Datafication of vision and care for unknown futures". *Big Data & Society*, *6*(1).

Agoston, M.K. and Agoston, M.K., 2005. *Computer graphics and geometric modeling* (Vol. 1, pp. 301-304). Springer.

Agriesti, S., Brevi, F., Gandini, P., Marchionni, G., Parmar, R., Ponti, M. and Studer, L. 2020. Impact of driverless vehicles on urban environment and future mobility. *Transportation Research Procedia*, *49*.

Aitken, S. and Craine, J. 2006. Guest editorial: Affective geovisualizations. *Directions Magazine*.

Aitken, S.C. and Craine, J. 2009. Into the image and beyond: Affective visual geographies and GIScience. *Qualitative GIS: A mixed methods approach*.

Ajayan, J. and Nirmal, D., 2015. A review of InP/InAlAs/InGaAs based transistors for high frequency applications. *Superlattices and Microstructures*, *86*.

Akerman, J.R. 1993. Blazing A Well-worn Path: Cartographic Commercialism, Highway Promotion, and Automobile Tourism in the United States, 1880-1930. *Cartographica: The International Journal for Geographic Information and Geovisualization*, 30(1).

Akerman, J. R. 2002. American Promotional Road Mapping in the Twentieth Century. *Cartography and Geographic Information Science*, 29(3).

Akter, B., & Iqbal, M. A. 2020. Failure Factors of Platform Start-ups: A Systematic Literature Review. *Nordic Journal of Media Management*, 1(3).

Alvarez León, L.F. 2016. Property regimes and the commodification of geographic information: An examination of Google Street View. *Big Data & Society*, *3*(2).

Alvarez León, L.F. 2019. Eyes on the road: surveillance logics in the autonomous vehicle economy. *Surveillance & Society*, *17*(1/2).

Amoore, L. 2006. Biometric borders: Governing mobilities in the war on terror. *Political geography*, *25*(3).

Amoore, L. 2009. Algorithmic war: Everyday geographies of the war on terror. *Antipode*, *41*(1).

Amoore, L. 2013. *The politics of possibility: Risk and security beyond probability*. Duke University Press.

Amoore, L. and Hall, A. 2010. Border theatre: On the arts of security and resistance. *cultural geographies* 17(3).

Analytics Insights. 2022. Top 100 Ai Unicorns and their success stories: a legendary path. https://www.analyticsinsight.net/top-100-ai-unicorns-and-their-success-stories-a-legendary-path/ Last accessed 5/3/2024.

Anderson, B. 2019. Cultural geography II: The force of representations. *Progress in Human Geography*, *43*(6).

Anderson, S. F. 2017. *Technologies of Vision: The War between Data and Images*. MIT Press.

Anderson, C. L. and Robinson, A. C. 2022. Affective Congruence in Visualization Design: Influences on Reading Categorical Maps. *IEEE Transactions on Visualization and Computer Graphics*, vol. 28, no. 8.

Andrejevic, M. 2017. Digital citizenship and surveillance| To Pre-empt a thief. *International Journal of Communication*, *11*.

Andrejevic, M. 2019. Automating Surveillance. In *Surveillance & Society, 17(1/2).*

Andrzejewski, A.V. 2008. *Building power: Architecture and surveillance in Victorian America*. University of Tennessee Press.

Angel, G. 2023. How Lidar improves airport operations. https://www.airport-technology.com/comment/how-lidar-improves-airport-operations/#catfish Last accessed 5/3/2024.

Appadurai, A. 1996. *Modernity at Large: Cultural Dimensions of Globalization.* Minnesota University Press.

Arbab-Zavar, B. and Sabeur, Z.A. 2020. Multi-scale crowd feature detection using vision sensing and statistical mechanics principles. *Machine Vision and Applications*, *31*.

Arena, F. and Ticali, D. 2018. November. The development of autonomous driving vehicles in tomorrow's smart cities mobility. In *AIP Conference Proceedings* (Vol. 2040, No. 1). AIP Publishing.

Arena, F. Pau, G. and Collotta, M. 2018. A survey on driverless vehicles: From their diffusion to security. *J. Internet Serv. Inf. Secur*, *8*.

Arena, F. Pau, G. and Severino, A. 2020. An overview on the current status and future perspectives of smart cars. *Infrastructures*, *5*(7).

Arshad, S. & Kim, G. W. 2021. Role of Deep Learning in Loop Closure Detection for Visual and Lidar SLAM: A Survey. *Sensors, 21(4).*

Ash, J. & Simpson, P. 2016. Geography and post-phenomenology. *Progress in Human Geography*, *40*(1).

Ash, J., Kitchin, R. and Leszczynski, A. 2018. Digital turn, digital geographies? *Progress in Human Geography* 42(1).

Ash, J., Anderson, B., Gordon, R. and Langley, P., 2018b. Unit, vibration, tone: A post-phenomenological method for researching digital interfaces. *cultural geographies*, *25*(1).

Atay, A. 2020. What is cyber or digital autoethnography?. *International Review of Qualitative Research*, *13*(3).

Bagloee, S.A., Tavana, M., Asadi, M. and Oliver, T. 2016. Autonomous vehicles: challenges, opportunities, and future implications for transportation policies. *Journal of modern transportation*, *24*.

Bahirat, K. and Prabhakaran, B. 2017. A study on lidar data forensics. In *2017 IEEE International Conference on Multimedia and Expo (ICME)*. IEEE.

Baker, G., Kindon, S. and Beausoleil, E., 2022. Danced movement in human geographic research: A methodological discussion. *Geography Compass*, *16*(8).

Balchin, W.G.V. and Coleman, A.M. 1967. Cartography and computers. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *4*(2).

Bansal P., Kockelman, K.M., Singh, A. 2016. Assessing public opinions of and interest in new vehicle technologies: An Austin perspective. In *Transportation Research Part C*, 67.

Barkan, R. 1972. Laser for war: New Scientist. *Survival*, *14*(5).

Barns, S. 2017. Visions of urban informatics: From proximate futures to data-driven urbanism. *The Fibreculture Journal* 29.

Barns, S. 2020. *Platform Urbanism: Negotiating Platform Ecosystems in Connected Cities*. Springer Link.

Barreneche, C. 2013. Book Review: Jussi Parikka, What Is Media Archaeology? *Media, Culture & Society*, *35*(8).

Barry, K. 2021. Unsettling the aesthetics of air travel through participatory tourist photography. *Tourist Studies*, *21*(3).

Barthes, R. 1957. *Mythologies*. French & European Pubns; 1st Edition.

Bartram, L., Patra, A. and Stone, M. 2017. Affective color in visualization. In *Proceedings of the 2017 CHI conference on human factors in computing systems*.

Batty, M. 2018. Artificial intelligence and smart cities. *Environment and Planning B: Urban Analytics and City Science*, *45*(1).

Bauman, Z. 2000. *Liquid Modernity*. Polity.

Bazin, A. 1967. The myth of total cinema. *What is cinema*, Vol. 1. University of California Press.

Bederman, D.J. 1998. Historic Salvage and the Law of the Sea. *U. Miami Inter-Am. L. Rev*.

Beer, D. 2009. Power through the algorithm? Participatory web cultures and the technological unconscious. *New Media & Society*, *11*(6).

Beer, D. 2017. The social power of algorithms. *Information*, *Communication & Society*, 20:1.

Beer, D. 2018. *The data gaze: Capitalism, power and perception*. Sage Publications.

Behringer, R., Sundareswaran, S., Gregory, B., Elsley, R., Addison, B., Guthmiller, W., Daily, R. and Bevly, D. 2004. The DARPA grand challenge-development of an autonomous vehicle. In *IEEE Intelligent Vehicles Symposium, 2004*.

Behroozpour, B., Sandborn, P.A., Wu, M.C. and Boser, B.E. 2017. Lidar system architectures and circuits. *IEEE Communications Magazine*, *55*(10).

Belfiore, M. 2007. Carnegie Takes First in DARPA's Urban Challenge. *Wired, November*, *4*. https://www.wired.com/2007/11/darpa-names-win/ Last accessed 5/3/2024.

Belkouri, D., Laing, R. and Gray, D. 2022. Through the eyes of Autonomous Vehicles–using laser scanning technology to engage the public via the analysis of journeys seen from a different perspective. *Transportation research procedia*, *60*.

Benjamin, R. 2023. Race after technology. *Social Theory Re-Wired* (Longhofer W. and Winchester D. eds.). Routledge.

Benjamin, W. B. 1969. *Illuminations*. Schocken Books.

Benjamin, J.J., Berger, A., Merrill, N. and Pierce, J. 2021. Machine learning uncertainty as a design material: a post-phenomenological inquiry. In *Proceedings of the 2021 CHI conference on human factors in computing systems*.

Bennett, M. M., Chen, J. K., Alvarez León, L. F., & Gleason, C. J. 2022. The politics of pixels: A review and agenda for critical remote sensing. *Progress in Human Geography*.

Berardi, F. 2011. *After the future*. AK Press Distribution.

Berardi, F. 2017. *Futurability: The age of impotence and the horizon of possibility*. Verso Books.

Bernard, H.R. 2017. *Research methods in anthropology: Qualitative and quantitative approaches*. Rowman & Littlefield.

Bertetto, P. 2003. *L'interpretazione dei film: dieci capolavori della storia del cinema*. Marsilio.

Bertetto, P. 2010. *La macchina del cinema*. Laterza.

Bertetto, P. 2006. *Metodologie di analisi del film*. Laterza.

Bertin, J. 1983. *Semiology of graphics*. University of Wisconsin Press.

Bertolotti, M. 2004. *The history of the laser*. CRC press.

Bharosa, N. 2022. The rise of GovTech: Trojan horse or blessing in disguise? A research agenda. *Government Information Quarterly*, *39*(3).

Bibri, S.E. 2019. The anatomy of the data-driven smart sustainable city: instrumentation, datafication, computerization and related applications. *Journal of Big Data*, *6*(1).

Birth, K. K. (2022). Capital flows, itinerant laborers, and time: A revision of Thompson's thesis of time and work discipline. *Time & Society*, *31*(3).

Bissell, D. 2018. Automation interrupted: How autonomous vehicle accidents transform the material politics of automation. *Political Geography*.

Bissell, D. and Fuller, G. 2017. Material politics of images: Visualising future transport infrastructures. *Environment and Planning A: Economy and Space*, *49*(11).

Bittner, C., Glasze, G. and Turk, C. 2013. Tracing contingencies: analyzing the political in assemblages of web 2.0 cartographies. *GeoJournal*, *78*.

Bonnefon, J.F., Shariff, A. and Rahwan, I. 2016. The social dilemma of autonomous vehicles. *Science*, *352*(6293).

Borenstein, J., Herkert, J. R., & Miller, K. W. 2017. Self-driving cars and engineering ethics: the need for a system level analysis. *Science and engineering ethics*. Apr (25)2.

Borges, J.L. (1999). On exactitude in science. *Collected fictions* (Borges J.L., ed; Hurley A., trans.). Penguin Books.

Bos, D. 2021. Geography and virtual reality. *Geography Compass*, *15*(9).

Boucher, P. 2015. Domesticating the drone: The demilitarisation of unmanned aircraft for civil markets. *Science and Engineering Ethics* 21(6).

Bountouri, L. and Giannakopoulos, G. 2014. The use of social media in archives. *Procedia-Social and Behavioral Sciences*, *147*.

Boyer, M.C. 1996. *CyberCities: visual perception in the age of electronic communication*. Princeton Architectural Press.

Braun, B. 2011. Governing disorder: Biopolitics and the molecularization of life. *Global Political Ecology* (Peet R., Robbins P. and Watts M. eds.). Routledge.

Bridge, G. 2013. Territory, now in 3D! *Political Geography* 34.

Brook, A., Ben-Dor, E. and Richter, R. 2010. Fusion of hyperspectral images and LiDAR data for civil engineering structure monitoring. In *2010 2nd Workshop on Hyperspectral Image and Signal Processing: Evolution in Remote Sensing*.

Brown, B. 2017. The Social Life of Autonomous Cars. *Computer* 50.

Brown, K. C. and Wiles, Kenneth W. 2020. The Growing Blessing of Unicorns: The Changing Nature of the Market for Privately Funded Companies. *Journal of Applied Corporate Finance* 32.

Browne, S. 2012. Everybody's got a little light under the sun: Black luminosity and the visual culture of surveillance. *Cultural Studies*, *26*(4).

Browne, S. 2015. *Dark Matters: On the Surveillance of Blackness.* Duke University Press.

Brughmans, T. and Peeples, M.A. 2023. *Network Science in Archaeology*. Cambridge University Press.

Bruno, I. 2009. The “Indefinite Discipline” of Competitiveness Benchmarking as a Neoliberal Technology of Government. *Minerva* 47.

Brusseau, J. 2023. Acceleration AI Ethics and the Debate between Stability AI’s Diffusion and OpenAI’s Dall-E. *International Conference on Computer Ethics* (Vol. 1, No. 1).

Buchan, S. (ed.) 2013. *Pervasive animation*. Routledge.

Bucher, T. 2018. *If...Then: Algorithmic Power and Politics.* Oxford University Press.

Bucher, E. and Fieseler, C. 2017. The flow of digital labor. *New media & society*, *19*(11).

Buchwald, J.Z. 1989. *The rise of the wave theory of light: Optical theory and experiment in the early nineteenth century*. University of Chicago Press.

Buchwald, J.Z. 2008. Descartes's experimental journey past the prism and through the invisible world to the rainbow. *Annals of Science*, *65*(1).

Burke, A. 2019. Occluded Algorithms. In *Big Data & Society*, 6 (2).

Burnham, J. 1969. Real time systems. *Artforum*, *8*(1).

Burrell, J. 2016. How the machine "thinks": understanding opacity in machine learning algorithms. In *Big Data & Society*, 3 (1).

Cabrales, A., Kendall, R. and Sánchez, A. 2019. Effective policies and social norms in the presence of driverless cars: Theory and experiment. CEPR Discussion Paper No. DP13784.

Caillois, R. 1939. *L'Homme et le sacré*. Gallimard.

Campbell, C.S. and Egbert, S.L. 1990. Animated cartography/Thirty years of scratching the surface. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *27*(2).

Campbell, J., De Haag, M.U., van Graas, F. and Young, S. 2003. Light detection and ranging-based terrain navigation-a concept exploration. *Proceedings of the 16th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GPS/GNSS 2003)*.

Cannelli, B. and Musso, M. 2022. Social media as part of personal digital archives: exploring users' practices and service providers' policies regarding the preservation of digital memories. *Archival Science*, *22*(2).

Cantamessa, M., Gatteschi, V., Perboli, G. and Rosano, M. 2018. Startups' roads to failure. *Sustainability*, *10*(7).

Caprotti, F. and Cowley R. 2019. Varieties of smart urbanism in the UK: discursive logics, the state, and local urban context. In *Trans Inst Br Geogr*;44(3).

Caprotti, F., Chang, IC.C. and Joss, S. 2022. Beyond the smart city: a typology of platform urbanism. *Urban Transform* 4, 4.

Cassetta, E., Marra, A., Pozzi, C. and Antonelli, P. 2017. Emerging technological trajectories and new mobility solutions. A large-scale investigation on transport-related innovative start-ups and implications for policy. *Transportation Research Part A: Policy and Practice*, *106*.

Castex, G. M. 1993. Frames of reference: The effects of ethnocentric map projections on professional practice. *Social Work, 38*(6).

Castells, M. 1991. *The Informational City: Information Technology, Economic Restructuring, and the Urban-Regional Process*. Blackwell.

Castells, M. 1997. An introduction to the information age. *City*, *2*(7).

Castells, M. 1999. Grassrooting the space of flows. *Urban Geography*, *20*(4).

Castells, M. 2004. Informationalism, networks, and the network society: a theoretical blueprint. *The network society: A cross-cultural perspective*.

Caton, S. and Haas, C. 2020. Fairness in machine learning: A survey. *ACM Computing Surveys*.

Cavoli, C., Phillips, B., Cohen, T., Jones, P. 2017. Social and behavioural questions associated with automated vehicles: A literature review. UCL Transport Institute. https://assets.publishing.service.gov.uk/media/5a7f934940f0b62305b87f9f/social-and-behavioural-questions-associated-with-automated-vehicles-literature-review.pdf Last accessed 5/3/2024.

Cayton, L. 2008. *Algorithms for manifold learning*. University of California Press.

CBInsights. 2018. Autonomous vehicles https://www.cbinsights.com/research/autonomous-vehicle-lidar-radar-startups-expert-intelligence/ last accessed 5/3/24.

Çelik, Z. 1997. *Urban Forms and Colonial Confrontations: Algiers under French Rule*. University of California Press.

Cetina, K.K. 1999 *Epistemic cultures: How the sciences make knowledge*. Harvard University Press.

Chase, A., Chase, D. and Chase, A. 2020. Ethics, new colonialism, and lidar data: A decade of lidar in Maya archaeology. *Journal of Computer Applications in Archaeology*, *3*(1).

Chiappino, S., Morerio, P., Marcenaro, L. and Regazzoni, C.S. 2015. Bio-inspired relevant interaction modelling in cognitive crowd management. *Journal of Ambient Intelligence and Humanized Computing*, *6*.

Chen, X. 2013. *Instrumental traditions and theories of light: The uses of instruments in the optical revolution* (Vol. 9). Springer Science & Business Media.

Chen, B. Y., Wang, Y., Wang, D., Li, Q., Lam, W. H. K., & Shaw, S.-L. 2018. Understanding the Impacts of Human Mobility on Accessibility Using Massive Mobile Phone Tracking Data. *Annals of the American Association of Geographers, 108(4).*

Chun, W. HK. 2011. *Programmed Visions: Software and Memory*. MIT Press.

Christin, A. 2020. The ethnographer and the algorithm: beyond the black box. *Theory and Society*, *49*(5-6).

Cixin, L. 2016. *The Three-Body Problem*. Tor Books.

Cloud, J. 2002. American cartographic transformations during the Cold War. *Cartography and Geographic Information Science* 29(3).

Cohen, A., Klassen, S. and Evans, D. 2020. Ethics in archaeological lidar. *Journal of Computer Applications in Archaeology*, *3*(1).

Cohen, J., Fung, A., Bernholz, L., Landemore, H. and Reich, R. 2021. Democracy and the digital public sphere. *Digital technology and democratic theory* (Bernholz, L., Landemore, H. and Reich, R. eds.). University of Chicago Press.

Coeckelbergh, M. 2020. Technoperformances: using metaphors from the performance arts for a postphenomenology and posthermeneutics of technology use. *AI & SOCIETY*, *35*(3).

Coeckelbergh, M. 2022. *The Political Philosophy of AI*. Polity.

Cohn, N. 2009. Real-Time Traffic Information and Navigation. *Transportation Research Record: Journal of the Transportation Research Board*, 2129(1).

Coldeway, D. 2017. WTF is Lidar? https://techcrunch.com/2017/02/12/wtf-is-lidar/ last accessed 8/5/23.

Cole, R., 2020. Vaporwave aesthetics: Internet nostalgia and the utopian impulse. *Asap/Journal*, *5*(2).

Cosgrove, D. 1985. Prospect, perspective and the evolution of the landscape idea. *Transactions of the Institute of British geographers*.

Cosgrove, D. 2001. *Apollo's eye: a cartographic genealogy of the earth in the western imagination*. JHU Press.

Cosgrove, D. 2005. Maps, mapping, modernity: Art and cartography in the twentieth century. *Imago Mundi*, *57*(1).

Cosgrove, D. 2006. Art and mapping: an introduction. *Cartographic perspectives*, (53).

Cosgrove, D. 2008. Cultural cartography: maps and mapping in cultural geography. In *Annales de géographie* (No. 2-3).

Costantino, D., Vozza, G., Pepe, M. and Alfio, V.S. 2022. Smartphone LiDAR Technologies for Surveying and Reality Modelling in Urban Scenarios: Evaluation Methods, Performance and Challenges. *Applied System Innovation*, *5*(4).

Crampton, J. and Wilson, M.W. 2015. Harley and friday harbor: A conversation with John Pickles. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *50*(1).

Crampton, J. W. 2009. Cartography: maps 2.0. *Progress in Human Geography*, *33*(1).

Crampton, J.W. 2016. Assemblage of the vertical: Commercial drones and algorithmic life. *Geographica Helvetica*, *71*(2).

Craine, J. and Aitken, S.C. 2011. The emotional life of maps and other visual geographies. In *Rethinking Maps* (pp. 167-184). Routledge.

Crang, M. 2001. Temporalised space and motion. *Timespace: Geographies of Temporality.* May, J. and Thrift, N. (eds.). Routledge.

Crary, J.1992. *Techniques of the observer: On vision and modernity in the nineteenth century*. MIT Press.

Crawford, K. (2021). *The atlas of AI: Power, politics, and the planetary costs of artificial intelligence*. Yale University Press.

Cronin, J.G. 2011. Excavating the Future: Taking an 'Archaeological'approach to technology. *Interdisciplinary Science Reviews*, *36*(1).

Cubitt, S. 1998. *Digital aesthetics*. SAGE.

Cubitt, S. 2014. *The practice of light. A genealogy of visual technologies from prints to pixels*. MIT Press.

Cubitt, S. 2015. Coherent light from projectors to fibre optics. *Digital light*. (Cubitt, S., Palmer, D. and Tkacz, N. eds.). Open Humanities Press.

Cugurullo, F. 2020. Urban artificial intelligence: From automation to autonomy in the smart city. *Frontiers in Sustainable Cities*, *2*.

Cugurullo F. 2021. *Frankenstein Urbanism. Eco, smart and autonomous cities, artificial intelligence and the end of the city*. Routledge.

Cugurullo, F., Caprotti, F., Cook, M., Karvonen, A., McGuirk, P., & Marvin, S. (2023). The rise of AI urbanism in post-smart cities: A critical commentary on urban artificial intelligence. *Urban Studies*, 00420980231203386.

Cunneen, M., Mullins, M., Murphy, F., Shannon, D., Furxhi, I. and Ryan, C. 2020. Autonomous vehicles and avoiding the trolley (dilemma): vehicle perception, classification, and the challenges of framing decision ethics. *Cybernetics and Systems*, *51*(1).

Cyr, D., Head, M., Larios, H., & Pan, B. 2009. Exploring Human Images in Website Design: A Multi-Method Approach. *MIS Quarterly*, *33*(3).

Dalton, C. M., & Thatcher, J. 2014. What does a critical data study look like, and why do we care? *In Society + Spa*ce, 20.

Datta, A. and Odendaal, N. 2019. Smart cities and the banality of power. *Environment and Planning D: Society and Space* 37(3).

De Guttry, A. and Capone, F. 2017. Do universities have a duty of care towards their employees and students when they travel abroad on university business? A critical analysis of the state-of-the-art and the relevant practice. *Interdisciplinary Political Studies*, *3*(1).

Deleuze, G. 1985/2019. Cinema II: the time-image. *Philosophers on Film from Bergson to Badiou: A Critical Reader* (Kul Want, C. ed.). Columbia University Press.

Deleuze, G. 1986/2018. *Foucault*. Orthotes.

Demantké, J., Mallet, C., David, N. and Vallet, B. 2012. Dimensionality based scale selection in 3D lidar point clouds. *The international archives of the photogrammetry, remote sensing and spatial information sciences*, *38*.

Dencik, L. 2018. Surveillance realism and the politics of imagination: Is there no alternative?. *Krisis: Journal for Contemporary Philosophy*, *2018*(1).

Denzin, N.K. and Lincoln, Y.S. (eds.) 2011. *The Sage handbook of qualitative research*. Sage.

Derrida, J. 1976. *Of grammatology.* (Spivak G. C. ed.). Johns Hopkins University.

Derrida, J. 1996. *Archive fever: A Freudian impression*. University of Chicago Press.

De Vletter, M. 2019. Don't Be Afraid of the Digital. In *Arts* (Vol. 8, No. 1, p. 6). MDPI.

Dholakia, S. 2019. Perception: How Self-Driving Cars 'See' the World. Available at: https://swarit.medium.com/perception-how-self-driving-cars-see-the-world-ae630636f4c Last accessed 27/03/24.

DiBiase, D., DeMers, M., Johnson, A., Kemp, K., Luck, A. T., Plewe, B. and Wentz, E. 2006. *Geographic Information Science and Technology Body of Knowledge.* Washington, D.C.: UCGIS and the Association of American Geographers.

Didion J (2005) *The Year of Magical Thinking*. Knopf.

Dijksterhuis, F.J., 2004. Once snell breaks down: From geometrical to physical optics in the seventeenth century. *Annals of science*, *61*(2).

Dikeç, M. 2015. *Space, politics and aesthetics*. Edinburgh University Press.

Dobrick, F.M., Fischer, J. and Hagen, L.M. 2018. *Research ethics in the digital age*. Springer Fachmedien Wiesbaden.

Dobson, J.E., 2023. *The Birth of Computer Vision*. University of Minnesota Press.

Dodge, M. 1997. Cybermap Atlas: envisioning the internet. *TeleGeography*, pp.63-68.

Dodge, M. 2014. Mapping and Geovisualization. *Approaches to human geography: Philosophies, theories, people and practices*. (Aitken, S.C. and Valentine, G. eds.) Sage.

Dodge, M. 2018. Mapping II: News media mapping, new mediated geovisualities, mapping and verticality. *Progress in Human Geography*, *42*(6).

Dodge, M. and Kitchin, R. 2000. Exposing the "second text" of maps of the net. *Journal of Computer-Mediated Communication*, *5*(4).

Dodge, M. and Kitchin, R. 2007. The automatic management of drivers and driving spaces. In *Geoforum*, 38(2).

Dodge, M. and Kitchen, R. 2011. *Code/Space: Software and Everyday Life*. MIT Press.

Dodge, M. and Kitchin, R. 2003. *Mapping cyberspace*. Routledge.

Doel, M.A. 1999. *Poststructuralist geographies: the diabolical art of spatial science*. Rowman & Littlefield.

Donegan, J.F. 2012. *Hutchie: The Life and Works of Edward Hutchinson Synge* (co-edited with D. Weaire and P. Florides). Living Edition.

Dong, P. and Chen, Q. 2017. *LiDAR remote sensing and applications*. CRC Press.

Dorling, D. (1992). Stretching space and splicing time: from cartographic animation to interactive visualization. *Cartography and Geographic Information Systems*, *19*(4).

Dou, W. and Krishnamurthy, S. 2007. Using Brand Websites to Build Brands Online: A Product versus Service Brand Comparison. *Journal of Advertising Research*, 47(2).

Dowling, R. and McGuirk, P. 2022. Autonomous vehicle experiments and the city. *Urban Geography*, 43:3.

Drozdz, M. 2020. Maps and Protest. *International Encyclopedia of Human Geography*. (Kitchin, R and Thrift, N. eds.). Elsevier.

Dromgoole, S. 1999. A note on the meaning of 'wreck'. *International Journal of Nautical Archaeology*, *28*(4).

Duarte, F. 2017. *Space Place and Territory: a critical review on spatialitis*. Routledge

Duarte, F. and Ratti, C. 2018. The Impact of Autonomous Vehicles on Cities: A Review. *Journal of Urban Technology, 1–16.*

Durkheim, E. 2016. The elementary forms of religious life. *Social theory re-wired*. Routledge.

Dwyer, C. and Davies, G. 2010. Qualitative methods III: animating archives, artful interventions and online environments. *Progress in Human Geography*, *34*(1).

Ebrahimi Soorchaei, B., Razzaghpour, M., Valiente, R., Raftari, A. and Fallah, Y.P. 2022. High-Definition Map Representation Techniques for Automated Vehicles. *Electronics*, *11*(20).

Edler, D. 2020. Where spatial visualization meets landscape research and "Pinballology": examples of landscape construction in pinball games. *KN-Journal of Cartography and Geographic Information*, *70*(2).

Edler, D. and Kühne, O. 2022. Deviant cartographies: A contribution to post-critical cartography. *KN-Journal of Cartography and Geographic Information*, *72*(2).

Edwards, P. N. 2002. Infrastructure and Modernity: Scales of Force, Time, and Social Organization in the History of Sociotechnical Systems. *Technology and Modernity*. (Misa, T.J., Brey, P. and Feenberg, A. eds.). MIT Press.

Elden, S. 2013. Secure the volume: Vertical geopolitics and the depth of power. *Political Geography* 34.

Elder-Vass, D. 2015. Disassembling actor-network theory. *Philosophy of the Social Sciences*, *45*(1).

Ellegård, K. (ed.) 2018. *Time geography in the global context: An anthology*. Routledge.

Elmaghraby, A. S. and Losavio, M. M. 2014. Cyber security challenges in Smart Cities: Safety, security and privacy. *Journal of Advanced Research, 5(4).*

Elsaesser, T., Simons, J. and Bronk, L. 1994. *Writing for the Medium: Television in transition*. Amsterdam University Press.

Elsaesser, T. 2004. *Harun Farocki: Working on the sight-lines*. Amsterdam University Press.

Elsaesser, T., 2004b. The new film history as media archaeology. *Cinémas*, *14*(2).

Elwood, S. 2021. Digital geographies, feminist relationality, Black and queer code studies: Thriving otherwise. *Progress in Human Geography*, *45*(2).

Elwood, S. and Leszczynski, A. 2013. New spatial media, new knowledge politics. *Transactions of the Institute of British Geographers* 38(4).

Elwood, S. and Leszczynski, A. 2018. Feminist digital geographies. *Gender, Place & Culture*, *25*(5).

Epstein, C. 2007. Guilty bodies, productive bodies, destructive bodies: Crossing the biometric borders. *International Political Sociology*, *1*(2).

Ernst, W. 2016. *Sonic time machines: Explicit sound, sirenic voices, and implicit sonicity*. Amsterdam University Press.

Ernst, W. 2017. *The Delayed Present: Media-Induced Tempor (e) alities & Techno-traumatic Irritations of "the Contemporary"*. Sternberg Press.

Etienne, H. 2020. When AI ethics goes astray: a case study of autonomous vehicles. *Soc Sci Comput Rev.*

Eubanks, V. 2018. *Automating inequality: How high-tech tools profile, police, and punish the poor*. St. Martin's Press.

Fagnant, D. J. and Kockelman, K. 2015. Preparing a nation for autonomous vehicles: opportunities, barriers and policy recommendations. *Transportation Research Part A: Policy and Practice, 77.*

Farocki, H. 2004. Phantom Images. *Public* 29.

Fatima, Z., Tanveer, M.H., Waseemullah, Zardari, S., Naz, L.F., Khadim, H., Ahmed, N. and Tahir, M., 2022. Production plant and warehouse automation with IoT and industry 5.0. *Applied Sciences*, *12*(4).

Fayjie, A.R.; Hossain, S.; Oualid D. and Lee, D.J. 2018. Driverless Car: Autonomous Driving Using Deep Reinforcement Learning in Urban Environment, *2018 15th International Conference on Ubiquitous Robots (UR)*, Honolulu, HI, USA, 2018.

Featherstone, M., Urry, J. and Thrift, N. 2005. *Automobilities*. SAGE.

Farinelli, F. 1981. Dallo spazio bianco allo spazio astratto: la logica cartografica. *Pesaggio: Immagine e Realtà*. (Maldonato, T. ed.) Electa.

Farinelli, F. 2003. *Geografia: un'introduzione ai modelli del mondo*. Einaudi.

Farinelli, F. 2009. *La crisi della ragione cartografica*. Einaudi.

Farinelli, F. 2016. *L'invenzione della Terra*. Sellerio Editore.

Fefferman, C., Mitter, S. and Narayanan, H. 2016. Testing the manifold hypothesis. *Journal of the American Mathematical Society*, *29*(4).

Feldman, A. 1997. Violence and vision: The prosthetics and aesthetics of terror. *Public Culture* 10(1).

Fernandez-Diaz, J.C., Cohen, A.S., González, A.M. and Fisher, C.T. 2018. Shifting perspectives and ethical concerns in the era of remote sensing technologies. *SAA Archaeological Record*, *18*.

Fernandez, J.C., Singhania, A., Caceres, J., Slatton, K.C., Starek, M. and Kumar, R. 2007. An overview of lidar point cloud processing software. *GEM Center Report No. Rep_2007-12-001, University of Florida*, *27*.

Ferrari, F. and Graham, M. 2021. Fissures in algorithmic power: platforms, code, and contestation. *Cultural Studies*, *35*(4-5).

Ferretti, F. 2020. History and philosophy of geography I: Decolonising the discipline, diversifying archives and historicising radicalism. *Progress in Human Geography*, *44*(6).

Fickers, A. and Oever, A. 2022. *Doing experimental media archaeology: Theory*. De Gruyter.

Fisher, K.T. 2015. Positionality, subjectivity, and race in transnational and transcultural geographical research. *Gender, Place & Culture*, *22*(4).

Fleetwood, J. 2017. Public health, ethics, and autonomous vehicles. *American journal of public health*, *107*(4).

Fleming, D. K. and Roth, R. 1991. Place in Advertising. *Geographical Review*, 81(3), 281.

Foster, H. 1988. Preface. *Vision and Visuality*. (Foster, A. ed.). Dia Art Foundation

Foucault, M. 1978. *The History of Sexuality, Volume 1: An Introduction.* Vol. 1. New York: Pantheon Books.

Foucault, M. 2003. *" Society Must Be Defended": Lectures at the Collège de France, 1975-1976* (Vol. 1). Macmillan.

Foucault, M., 2023. (1975) *Discipline and punish*. Routledge.

Francaviglia, R. 2005. Cover the Earth: Maps in advertising and promotion. *Mimeo*.

Frederiksen, D.L. and Brem, A. 2017. How do entrepreneurs think they create value? A scientific reflection of Eric Ries' Lean Startup approach. *International Entrepreneurship and Management Journal*, *13*.

Freud, S. 1989. The ego and the id (1923). *TACD Journal*, *17*(1).

Freud, S., 2015. *Civilization and its discontents (1930)*. Broadview Press.

Frith, J. 2013. Turning life into a game: Foursquare, gamification, and personal mobility. *Mobile Media & Communication*, *1*(2).

Gaboury, J. 2021. *Image objects: An archaeology of computer graphics*. MIT Press.

Galison, P. 2004. Removing knowledge. *Critical Inquiry*, *31*(1).

Galison, P. and May, J. 2014. *The Revelation of Secrets: Peter Galison and Jhon May on artifacts of surveillance, part I, part II*. Interview available here: https://galison.scholar.harvard.edu/files/andrewhsmith/files/galison_may_interview_thresholds.pdf Last accessed 5/3/24.

Galloway, A. R. 2012. *The Interface Effect*. Polity.

Gargiulo, E. 2022. 'Crowds are mad and criminal': the notion of public order in Italian manuals for police mobile units, 2000–2008, Journal of Modern Italian Studies, 27:2.

Gargoum, S. and El-Basyouny, K. 2017. Automated extraction of road features using LiDAR data: A review of LiDAR applications in transportation. In *2017 4th International Conference on Transportation Information and Safety (ICTIS)* (pp. 563-574). IEEE.

Garland, K. 1994. *Mr Beck's underground map: a History*. Capital Transport Publishing.

Garroni, E. 1982. *Estetica: uno sguardo-attraverso.* Castelvecchi.

Gekker, A. and Hind, S. 2020. Infrastructural surveillance. *New Media & Society*, *22*(8).

Gilbert, M. 2010. Theorizing digital and urban inequalities: Critical geographies of 'race', gender and technological capital. *Information, Communication & Society* 13(7).

Gilge, C. 2016. Google Street View and the Image as Experience, *GeoHumanities*, 2:2.

Glasze, G., Cattaruzza, A., Douzet, F., Dammann, F., Bertran, M.G., Bômont, C., Braun, M., Danet, D., Desforges, A., Géry, A. and Grumbach, S. 2023. Contested spatialities of digital sovereignty. *Geopolitics*, *28*(2).

Glissant, É. 1997. *Poetics of relation*. University of Michigan Press.

Goddard, M. 2015. Opening up the black boxes: Media archaeology,'anarchaeology'and media materiality. *New Media & Society*, *17*(11).

Goffe, T.L. 2020. Unmapping the Carabbean: Towards a digital praxis of archipelagic sounding. *Archipelagos* 5.

Golden, J.P. 1980. December. Terrain contour matching (TERCOM): a cruise missile guidance aid. In *Image processing for missile guidance* (Vol. 238). SPIE.

Goldman, R. and Papson, S. 2011. *Landscapes of Capital: Representing Time, Space, and Globalization in Corporate Advertising.* Polity Press.

Goldstein, K. 2002. Getting in the door: Sampling and completing elite interviews. *PS: Political Science & Politics*, *35*(4).

Goodfellow, I., Bengio, Y. and Courville, A. 2016. *Deep learning*. MIT press.

Gorban, A.N. and Tyukin, I.Y. 2018. Blessing of dimensionality: mathematical foundations of the statistical physics of data. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*, *376*(2118).

Gordon, J.P., Zeiger, H.J. and Townes, C.H. 1955. The maser—new type of microwave amplifier, frequency standard, and spectrometer. *Physical review*, *99*(4).

Gössling, S.; Cohen, S.A., Hares, A. 2016. Inside the black box: EU policy officers' perspectives on transport and climate change mitigation. In *Journal of Transport Geography*, 57.

Graham, M. 2010. Neogeography and the palimpsests of place: Web 2.0 and the construction of a virtual earth. *Tijdschrift voor economische en sociale geografie*, *101*(4).

Graham, M. and Shelton, T. 2013. Geography and the future of big data, big data and the future of geography. *Dialogues in Human geography*, *3*(3).

Graham, M., Straumann, R.K. and Hogan, B., 2015. Digital divisions of labor and informational magnetism: Mapping participation in Wikipedia. *Annals of the Association of American Geographers*, *105*(6).

Graham, M., Zook, M. and Boulton, A. 2022. Augmented reality in urban places: contested content and the duplicity of code. *Machine Learning and the City: Applications in Architecture and Urban Design*.

Graham, S. (ed.) 2010. *Disrupted cities: When infrastructure fails*. Routledge.

Graham S. and Marvin S. 2001. *Splintering Urbanism: Networked Infrastructures, Technological Mobilities and the Urban Condition*. Routledge.

Graham, S. and Hewitt, L., 2013. Getting off the ground: On the politics of urban verticality. *Progress in Human Geography*, *37*(1).

Gray, M. 2009. *Out in the Country: Youth, Media, and Queer Visibility in Rural America*. NYU Press.

Gren, M. 2001. Time-geography matters. *Timespace: Geographies of temporality*.

Gross, M. 2004. Human geography and ecological sociology: The unfolding of a human ecology, 1890 to 1930—and beyond. *Social Science History*, *28*(4).

Gržinić, M. 1999. The Virtual-Image and the Real-Time Interval. *Filozofski vestnik*, *20*(2).

Guo, F., Nanda, V.K. and Pevzner, M. 2016. The effects of trade secret protections on financial reporting opacity: Evidence from a natural experiment. Available at SSRN: https://ssrn.com/abstract=2808144.

Haklay, M. 2017. Information And Citizen Science. *Understanding spatial media*. (Kitchin, R., Lauriault, T. and Wilson, M. eds.). Sage.

Halpern, O. 2015. *Beautiful data: A history of vision and reason since 1945*. Duke University Press.

Hao, S., Zhou, Y. and Guo, Y. 2020. A brief survey on semantic segmentation with deep learning. *Neurocomputing*, *406*.

Haraway, D. 1996. *Modest_Witness@ Second_Millennium. FemaleMan_Meets_OncoMouse: feminism and technoscience*. Routledge.

Haraway, D. 2013. *Simians, cyborgs, and women: The reinvention of nature*. Routledge.

Harley, J. B. 1992. Deconstructing the map. Barnes, T. J. and Duncan J. S. (eds) *Writing Worlds: Discourse, Text and Metaphor in the Representation of Landscape.* Routledge.

Harris, M. 2014. The unknown start-up that built Google's first self-driving car. *IEEE Spectr*.

Harris, R. L. 2000. *Information Graphics: A Comprehensive Illustrated Reference*. Oxford University Press.

Harvey, D. 1990. Between space and time. *Annals of the Association of American Geographers* 80.

Harvey, W. S. 2011. Strategies for conducting elite interviews. *Qualitative Research, 11(4).*

Harrower, M. 2004. A look at the history and future of animated maps. *Cartographica: The International Journal for Geographic Information and Geovisualization*, *39*(3).

Hasecke, F., Alsfasser, M. and Kummert, A. 2022. What can be seen is what you get: Structure aware point cloud augmentation. *IEEE Intelligent Vehicles Symposium (IV)*.

Hawkins, A. J. 2021. Volvo bucks the industry, will sell LIDAR-equipped self-driving cars to customers by 2022. https://www.theverge.com/2020/5/6/21248415/volvo-luminar-lidar-self-driving-highway-pilot-spa2. Last accessed 14 Septmber 2023.

Hayles, N.K. 1999. *How we became posthuman: virtual bodies in cybernetics, literature, and informatics.* University of Chicago Press.

Hayles, N.K. 2004. Bodies of texts, bodies of subjects: Metaphoric networks in new media. *Memory Bytes: History, Technology, and Digital Culture*. Rabinovitz, L. and Geil, A. (eds.). Duke University Press.

Heelan, P.A. 1991. Hermeneutical phenomenology and the philosophy of science. *Gadamer and hermeneutics: science, culture, and literature*. (Silverman H. ed.). Routledge.

Hepach, M. G. 2021. Entangled phenomenologies: Reassessing (post-)phenomenology's promise for human geography. *Progress in Human Geography*, *45*(5), 1278-1294.

Hernandez-Suarez, A., Sanchez-Perez, G., Toscano-Medina, K., Toscano-Medina, R., Martinez-Hernandez, V., Olivares-Mercado, J. And Sanchez, V. 2018. Can Twitter API Be Bypassed? A New Methodology for Collecting Chronological Information Without Restrictions. In *SoMeT*.

Hesse-Biber, S.N. and Leavy, P. 2010. *The practice of qualitative research*. Sage.

Hind, S. 2019. Digital Navigation and the Driving-Machine: Supervision, Calculation, Optimization, and Recognition. *Mobilities*. 14 (4).

Hind, S. 2021. Dashboard Design and the 'Datafied' Driving Experience. *Big Data & Society*. 8 (2).

Hind, S. 2022. Machinic Sensemaking in the Streets: More-than-Lidar in Autonomous Vehicles,'. *Seeing the City Digitally*. (Rose, G. ed.). Oapen.

Hind, S. 2023. Sensor work: enabling the interoperation of autonomous vehicles. *Journal of Computer-Mediated Communication*, *28*(5).

Hind, S., and Gekker, A. 2022. Automotive parasitism: Examining Mobileye's 'car-agnostic' platformisation. *New Media & Society*.

Ho, B. 2018. *Making a New City Image*. Available at: https://papers.cumincad.org/data/works/att/acadia20_658.pdf Last accessed 14/03/2024.

Hodgetts, D. 2009. LiDAR in the environmental sciences: geological applications. *Laser scanning for the environmental sciences*, pp.165-179.

Hoffmann, E.T.A. 2014. *Der Sandmann/Das Fräulein von Scuderi*. Suhrkamp Verlag.

Hoelzl, I. and Marie, R. 2014. Google Street View: navigating the operative image. *Visual Studies*, *29*(3).

Holford, W.D. 2019. The future of human creative knowledge work within the digital economy,

Futures, Volume 105.

Hooper, J. 2004. From Darpa Grand Challenge 2004DARPA's Debacle in the Desert. https://www.popsci.com/scitech/article/2004-06/darpa-grand-challenge-2004darpas-debacle-desert/. Last accessed 5/3/24.

Hoth, J. 2021. Creative Technologies and Interdisciplinary Collaboration: A case study on the Aspen Movie Map. *10th International Conference on Digital and Interactive Arts*.

Hughes, C. B., Taylor L. R. and Williams E. B. 1990. *Bundle Theories for Topological Manifolds. Transactions of the American Mathematical Society, 319(1).*

Hui, Y. 2017. On Cosmotechnics: For a Renewed Relation between Technology and Nature in the Anthropocene. *Techne: Research in Philosophy & Technology*, *21*.

Huhtamo, E. 1999. From cybernation to interaction: a contribution to an archaeology of interactivity. *The digital dialectic: New essays on new media*, (s 96).

Huhtamo, E. 2006. Elements of screenology: Toward an archaeology of the screen. *Navigationen-Zeitschrift für Medien-und Kulturwissenschaften*, *6*(2).

Huhtamo, E. 2020. The Self-Driving Car: A Media Machine for Posthumans? *Artnodes*, 2020, Num. 26.

Huhtamo, E. and Parikka, J. (eds.) 2011. *Media archaeology: Approaches, applications, and implications*. Univiversity of California Press.

Hullot-Kentor, R. 2018. Metric of Rebarbarization: Real Time in The Authoritarian Personality. *South Atlantic Quarterly*, *117*(4).

Human, O. and Cilliers, P. 2013. Towards an economy of complexity: Derrida, Morin and Bataille. *Theory, Culture & Society*, *30*(5).

Hunger, F. 2023. Unhype Artificial 'Intelligence'! A proposal to replace the deceiving terminology of AI. Zenodo. Working paper available at https://zenodo.org/records/7524493. Last accessed 5/3/2024.

Hopkins, D. and Schwanen, T. 2018. Experimentation with vehicle automation. *Transitions in energy efficiency and demand* (Jenkins, K.H.E. and Hopkins, D. eds.). Routledge.

Hopkins, D. and Schwanen, T. 2018b. Governing the race to automation. *Governance of the smart mobility transition*. (Marsden, G. and Reardon, L. eds.). Emerald Publishing Limited.

Hopkins, D. and Schwanen, T. 2021. Talking about automated vehicles: What do levels of automation do? *Technology in Society*, *64*.

Hopkins, D. and Schwanen, T. 2022. Recruiting research participants for transport research: Reflections from studies on autonomous vehicles in the UK. *Journal of transport geography*, *102*.

Ihde, D. 1979. *Technics and Praxis*. Reidel Publishing Company.

Ihde, D. 1990. *Technology and the Lifeworld: From Garden to Earth*. Indiana University Press.

Ihde, D. 1998. Whole earth measurements. *Ludus Vitalis, Journal of Philosophy of the Life Sciences*, *2*.

Ihde, D. 1999. Expanding hermeneutics. *Hermeneutics and Science: Proceedings of the First Conference of the International Society for Hermeneutics and Science*. Springer.

Ihde, D. 2000. Epistemology engines. *Nature*, *406*(6791).

Ihde, D. 2006. Models, models everywhere. *SOCIOLOGY OF THE SCIENCES*, *25*.

Ihde, D. 2006b. The Designer Fallacy and Technological Imagination. *Defining Technological* Literacy. (Dakers, J.R. ed.). Palgrave Macmillan.

Ihde, D. 2009. *Postphenomenology and Technoscience: The Peking University Lectures*. SUNY Press.

Ihde, D. 2012. 'Cartesianism' Redux or Situated Knowledges. *Found Sci 17*.

Ihde, D. 2015. Preface: positioning postphenomenology. *Postphenomenological investigations: essays on human-technology relation*s. (Rosenberger, R. and Verbeek P.P. eds.). Lexington Books.

Ihde, D., & Selinger, E. (2004). Merleau-Ponty and epistemology engines. *Human Studies*, *27*, 361-376.

Iliadis, A. and Russo, F. 2016. Critical data studies: An introduction. *Big Data & Society*. 3 (2).

Jackman, A. 2022. Domestic drone futures. *Political Geography*, *97*.

Jackman, A. and Brickell, K. 2022. 'Everyday droning': Towards a feminist geopolitics of the drone-home. *Progress in Human Geography*, *46*(1).

Jackson, R.W. 2004. The impacts of Walter Isard on geography. *Journal of geographical systems*, *6*.

Jay, M. 1988. Scopic regimes of modernity. *Vision and Visuality* (Foster, H. ed.). Bay Press.

Jefferson, B.J. 2017. Digitize and punish: Computerized crime mapping and racialized carceral power in Chicago. *Environment and Planning D: Society and Space* 35(5).

Jefferson, B. J. 2018. Computerizing carceral space: Coded geographies of criminalization and capture in New York City. *Environment and Planning A: Economy and Space* 50(5).

Jiang, B. and Ormeling, F.J. 1997. Cybermap: The Map for Cyberspace. *The Cartographic Journal* 34, 2.

Jones, R., Sadowski, J., Dowling, R., Worrall, S., Tomitsch, M. and Nebot, E. 2023. Beyond the driverless car: A typology of forms and functions for autonomous mobility. *Applied Mobilities*, *8*(1).

Kalluri, P.R., Agnew, W., Cheng, M., Owens, K., Soldaini, L. and Birhane, A. 2023. The Surveillance AI Pipeline. *arXiv preprint arXiv:2309.15084*.

Kalman, R.E. 1960. A new approach to linear filtering and prediction problems. *Journal of Basic Engineering*, 82 (1).

Kanaujiya, A.K. and Tiwari, V., 2022. Crowd management and strategies for security and surveillance during the large mass gathering events: The Prayagraj Kumbh Mela 2019 Experience. *National Academy science letters*, *45*(3).

Karlin-Resnick, J., Tumlin, J. and Merritt, M. 2018. Policy and program innovation in anticipation of the new mobility future. In *Disruptive Transport* (pp. 98-124). Routledge.

Karvonen, A. and Van Heur, B. 2014. Urban laboratories: Experiments in reworking cities. *International Journal of Urban and Regional Research*, *38*(2).

Kassens-Noor, E. and Hintze, A. 2020. Cities of the future? The potential impact of artificial intelligence. *AI*, *1*(2).

Kaur, K. and Rampersad, G. 2018. Trust in driverless cars: Investigating key factors influencing the adoption of driverless cars. *Journal of Engineering and Technology Management*, *48*.

Keith, M.E. (ed.) 2016. *Site formation processes of submerged shipwrecks*. University Press of Florida.

Kellerman, A. 1989. *Time, Space, and Society: Geographical Societal Perpectives* (Vol. 11). Springer Science & Business Media.

Kellerman, A. 2018. *Automated and autonomous spatial mobilities*. Edward Elgar Publishing.

Kelley, M. 2018. Framing digital exclusion in technologically mediated urban spaces. *Thinking Big Data in Geography*. (Thatcher, J., Eckert, J. and Shears, S. eds.). University of Nebraska Press.

Kellner, D. 1999. Virilio, war and technology: Some critical reflections. *Theory, Culture & Society*, *16*(5-6).

Kenderdine, S. and Yep, A. 2019. The proliferation of Aura: Facsimiles, authenticity and digital objects. *The Routledge Handbook of Museum, Media and Communication*. (Drotner, K., Dziekan, V., Parry, R. and Schrøder, K.C eds.). Routledge.

Kennedy, H. and Hill, R.L. 2018. The feeling of numbers: Emotions in everyday engagements with data and their visualisation. *Sociology*, *52*(4).

Kim, Y. and Bang, H., 2018. Introduction to Kalman filter and its applications. *Introduction and Implementations of the Kalman Filter*, *1*.

Kitchin, R. 2014. The real-time city? Big data and smart urbanism. *GeoJournal*, *79*.

Kitchin, R. 2014b. Big Data, new epistemologies and paradigm shifts. *Big data & society*, *1*(1), p.2053951714528481.

Kitchin, R. 2021. The Data Revolution: A critical analysis of big data, open data and data infrastructures. *The Data Revolution*.

Klauser, F. 2016. *Surveillance and Space.* SAGE Publications.

Koyré, A., 1957. *From the closed world to the infinite universe* (Vol. 1). Library of Alexandria.

Koskela, H. 2000. 'The gaze without eyes': video-surveillance and the changing nature of urban space", *Progress in Human Geography* Volume: 24 issue: 2.

Kostelnick, C. 2016. The Re-Emergence of Emotional Appeals in Interactive Data Visualization. *Technical Communication* 63, no. 2.

Kraak, M. J. and Ormeling, F. 2010. Cartography: visualization of geospatial data. ESRI Press.

Kraftl ,P. 2014. Liveability and urban architectures: Mol(ecul)ar biopower and the becoming lively of sustainable communities. *Environment and Planning D: Society and Space* 32.

Krauss, R. 1977. Video: The aesthetics of narcissism. *October*.

Krauss, R. 1988. The Impulse to See. *Vision and Visuality*. Foster, A. (ed). Dia Art Foundation

Krauss, R. 1993. *The Optical Unconscious*. MIT Press.

Kristjánsson, L. 2012. Iceland spar and its legacy in science. *History of Geo-and Space Sciences*, *3*(1).

Krotov, V. and Johnson, L. 2023. Big web data: Challenges related to data, technology, legality, and ethics. *Business Horizons*, *66*(4).

Krueger, R., Rashidi, T.H. and Rose, J.M. 2016. Preferences for shared autonomous vehicles. In *Transportation Research Part C*, 69.

Kullmann, K. 2018. The drone's eye: applications and implications for landscape architecture. *Landscape Research*, *43*(7).

Kurgan, L. 2013. *Close up at a distance: Mapping, technology, and politics*. MIT Press.

Kurgan, L. 2017. Conflict urbanism, Aleppo: Mapping urban damage. *Architectural Design* 87(1).

de Landa, M.D. 1991. *War in the age of intelligent machines*. Zone Books.

Langton, S.H. and Steenbeek, W. 2017. Residential burglary target selection: An analysis at the property-level using Google Street View. *Applied Geography*, *86*.

Lanzing, M. 2016. The transparent self. *Ethics and Information Technology*, *18*.

Lapenta, F. 2012. Geomedia-Based Methods and Visual Research: Exploring Theoretical Tenets of the Localization and Visualization of Mediated Social Relations with Direct Visualization. *Techniques, Advances in Visual Methodology*. (Pink, S. ed.). SAGE.

Larkin, B. 2013. The politics and poetics of infrastructure. *Annual review of anthropology*, 42, 327–343.

Lasch, C. 1983. The Modernist Myth of the Future. *Revue Française d'études Américaines,* no. 16 (1983).

Latham, A. and McCormack, D.P. 2009. Thinking with images in non□representational cities: vignettes from Berlin. *Area*, *41*(3).

Latour, B. 1999. *Pandora's hope: essays on the reality of science studies*. Harvard University Press.

Latour, B. 2010. Networks, Societies, Spheres: Reflections of an Actor-Network Theorist. Keynote Speech for the International Seminar on Network Theory: Network Multidimensionality in the Digital Age. *Annenberg school for Communication and Journalism*.

Latour, B. (2012). Introduction: Paris, invisible city: The plasma. *City, Culture and Society*, *3*(2).

Latour, B. and Lowe, A. 2020. The migration of the aura, or how to explore the original through its facsimiles. *The Aura in the Age of Digital Materiality: Rethinking preservation in the shadow of an uncertain future.* (Lowe, A., Mitchell, E., Béliard, N., Fornaciari, G., Tomassini, T. and Damone, G eds.). SilvanaEditoriale.

Leal Filho, W., Wall, T., Rayman-Bacchus, L., Mifsud, M., Pritchard, D.J., Lovren, V.O., Farinha, C., Petrovic, D.S. and Balogun, A.L. 2021. Impacts of COVID-19 and social isolation on academic staff and students at universities: a cross-sectional study. *BMC public health*, *21*(1).

Lee, C., 2017. Grabbing the wheel early: Moving forward on cybersecurity and privacy protections for driverless cars. *Fed. Comm. LJ*, *69*.

Legacy, C., Ashmore, D., Scheurer, J., Stone, J. and Curtis, C., 2019. Planning the driverless city. *Transport reviews*, *39*(1).

Lenoir, J., Gril, E., Durrieu, S., Horen, H., Laslier, M., Lembrechts, J.J., Zellweger, F., Alleaume, S., Brasseur, B., Buridant, J. and Dayal, K. 2022. Unveil the unseen: Using LiDAR to capture time□lag dynamics in the herbaceous layer of European temperate forests. *Journal of Ecology*, *110*(2).

Levine, D.S. 2007. Secrecy and unaccountability: Trade secrets in our public infrastructure. *Fla. L. Rev.*, *59*.

Levitt, T. 2009. *The Shadow of Enlightenment: Optical and Political Transparency in France 1789- 1848*. Oxford University Press

Levy, K. E., & Johns, D. M. 2016. *When open data is a Trojan Horse: The weaponization of transparency in science and governance. Big Data & Society, 3(1), 205395171562156.*

Leszczynski, A. 2011. Situating the geoweb in political economy. *Progress in Human* Geography, 36(1).

Leszczynski, A. 2015. Spatial media/tion. *Progress in Human Geography* 39(6).

Leszczynski, A. and Crampton, J. 2016. Introduction: Spatial Big Data and everyday life. *Big Data & Society*, *3*(2).

Leszczynski, A. 2020. Glitchy vignettes of platform urbanism. *Environment and Planning D: Society and Space*, *38*(2).

Leszczynski, A. 2019. 'Digital methods II: Digital-visual methods'. *Progress in Human Geography*, 43(6).

Li, W., Wang, Z., Wei, G., Ma, L., Hu, J. and Ding, D., 2015. A survey on multisensor fusion and consensus filtering for sensor networks. *Discrete Dynamics in Nature and Society*, *2015*.

Li, X., Zhang, C. and Li, W. 2017. Building block level urban land-use information retrieval based on Google Street View images. *GIScience & Remote Sensing*, *54*(6).

Li, Y. and Xie, Y., 2020. Is a picture worth a thousand words? An empirical study of image content and social media engagement. *Journal of Marketing Research*, *57*(1).

Li, N., Ho, C.P., Xue, J., Lim, L.W., Chen, G., Fu, Y.H. and Lee, L.Y.T. 2022. A progress review on solid□state LiDAR and nanophotonics□based LiDAR sensors. *Laser & Photonics Reviews*, *16*(11).

Liberati, N. 2016. Augmented reality and ubiquitous computing: the hidden potentialities of augmented reality. *AI Soc* 31(1).

Light, B., Burgess, J. and Duguay, S. 2018. The walkthrough method: An approach to the study of apps. *New media & society*, *20*(3).

Lin, S., Chen, Y. and Wong, Z.J., 2022. High-performance optical beam steering with nanophotonics. *Nanophotonics*, *11*(11).

Liu, J., Sun, Q., Fan, Z. and Jia, Y. 2018. TOF lidar development in autonomous vehicle. *2018 IEEE 3rd Optoelectronics Global Conference (OGC)*. IEEE.

Liu, R., Wang, J., & Zhang, B. 2019. High Definition Map for Automated Driving: Overview and Analysis. *Journal of Navigation*, 73(2).

Lomborg, S. 2012. Personal internet archives and ethics. *Research Ethics*, 9(1).

Longley, P. A., Goodchild, M. F., Maguire, D. J., & Rhind, D. W. 2015. *Geographic information systems and science*. John Wiley & Sons.

Lorinc, J. 2022. *Dream states: Smart cities, technology, and the pursuit of urban utopias*. Coach House Books.

Lu, S. 2020. Algorithmic opacity, private accountability, and corporate social disclosure in the age of artificial intelligence. *Vand. J. Ent. & Tech. L.*, *23*.

Lübbe, H. 2009. The Contraction of the Present. *High-speed society: social acceleration, power, and modernity*. Hartmut Rosa and William Scheuerman (eds.) p 159-79. Pennsylvania State University.

Luetzenburg, G., Kroon, A. and Bjørk, A.A., 2021. Evaluation of the Apple iPhone 12 Pro LiDAR for an application in geosciences. *Scientific reports*, *11*(1).

Lynch, K. 1960. *The image of the City*. MIT Press.

Lyon, D. 2007. *Surveillance Studies: An Overview*. Polity Press.

Lyon, D. 2022. Reflections on Forty Years of "Surveillance Studies". *Surveillance & Society*, *20*(4).

Maalsen, S. 2023. Algorithmic epistemologies and methodologies: Algorithmic harm, algorithmic care and situated algorithmic knowledges. *Progress in Human Geography*, *47*(2), pp.197-214.

Magnusson, T. 2009. Of epistemic tools: Musical instruments as cognitive extensions. *Organised Sound*, *14*(2).

Magris, C. 2019. *Polene*. La Nave di Teseo Editore.

Melgaço, L. and van Brakel, R. 2021. Smart cities as surveillance theatre. *Surveillance & Society*, *19*(2).

Makai, A.L. 2021. Startup Ecosystem Rankings. *Hungarian Statistical Review* 4.2: 70-94.

Makantasis, K., Liapis, A. and Yannakakis, G.N. 2019. From pixels to affect: A study on games and player experience. In *2019 8th International Conference on Affective Computing and Intelligent Interaction (ACII)*. IEEE.

Mamiani, M. 1976. *Isaac Newton filosofo della natura: le lezioni giovanili di otica e la genesi del metodo newtoniano.* La nuova casa editrice.

Mann, S., Havens, J.C., Iorio, J., Yuan, Y. and Furness, T. 2018. All reality: values, taxonomy, and continuum, for virtual, augmented, eXtended/MiXed (X), Mediated (X, Y), and multimediated reality/intelligence. *Presented at the AWE 2018*.

Manovich, L. 2002. *The language of new media*. MIT press.

Marres, N. 2020. What if nothing happens? Street trials of intelligent cars as experiments in participation. *TechnoScienceSociety: Technological reconfigurations of science and society*. (Maassen, S., Dickel, S. and Schneider, C.H. eds.). Sociology of the Sciences Yearbook, vol 30. Springer.

Marres, N., & Stark, D. (2020). Put to the test: For a new sociology of testing. In *The British Journal of Sociology*, 71(3).

Massey, D. 1992. Politics and space/time *New Left Review* 196.

Massey, D. 1999. Space-time, 'science' and the relationship between physical geography and human geography *Transactions of the Institute of British Geographers* 24 26.

Massey, D. 2005. *For Space.* Sage.

Massey, D., 2012. Power-geometry and a progressive sense of place. *Mapping the futures: Local cultures, global change*. (Bird, J., Curtis, B., Putnam, T. and Tickner, L. eds.). Routledge.

Merriam, S.B. and Tisdell, E.J. 2015. *Qualitative research: A guide to design and implementation*. John Wiley & Sons.

MacEachren, A.M. 2004. *How maps work: representation, visualization, and design*. Guilford Press.

MacEachren, A. M. 1979. The evolution of thematic cartography: A research methodology and historical review. *The Canadian Cartographer*, 16.

Mackenzie, A. and Munster, A. 2019. Platform seeing: Image ensembles and their invisualities. *Theory, Culture & Society*, *36*(5).

Marshall, J. and Adamic, M. 2010. The story is the message: shaping corporate culture. *Journal of Business strategy*, *31*(2).

Martínez-Díaz, M. and Soriguera, F., 2018. Autonomous vehicles: theoretical and practical challenges. *Transportation Research Procedia*, *33*.

Marx, G.T. 2015. *Windows into the Soul: Surveillance and Society in an Age of High Technology.* University of Chicago Press.

Marx, G.T. and Guzik, K. 2017. The uncertainty principle: Qualification, contingency and fluidity in technology and social control. *The Routledge handbook of technology, crime and justice*. (McGuire, M. and Holt, T.J. eds.). Routledge.

Massumi, B. 2007. Potential politics and the primacy of preemption. *Theory & Event*, *10*(2).

Mattern, S. 2018. Databodies in codespace. *Places Journal*, April 2018.

Mattern, S. 2020. A city is not a computer. In *The Routledge Companion to Smart Cities*. (Willis, K.S. and Aurigi, A. eds.). Routledge.

Mbembe, A. 2002. The Power of the Archive and its Limits. In *Refiguring the archive*. (Hamilton, C., Harris, V., Taylor, J., Pickover, M., Reid, G. and Saleh, R. eds.). Springer.

Mbembe, A. 2011. *Necropolitics*. Duke University Press.

McBride, N. 2016. The ethics of driverless cars. *Acm Sigcas Computers and Society*, *45*(3), pp.179-184.

McManamon, P.F. 2019. Design considerations for an auto LiDAR. In *ODS 2019: Industrial Optical Devices and Systems* (Vol. 11125). SPIE.

McCosker, A. and Wilken, R. 2020. *Automating vision: The social impact of the new camera consciousness*. Routledge.

McCormack, D.P., 2008. Geographies for moving bodies: Thinking, dancing, spaces. *Geography Compass*, *2*(6).

McCormack, D.P. 2010. Remotely sensing affective afterlives: The spectral geographies of material remains. *Annals of the Association of American Geographers*, *100*(3).

McCormack, D.P. 2017. The circumstances of post□phenomenological life worlds. *Transactions of the Institute of British Geographers*, *42*(1).

McNeill, D. 2016. Governing a City of Unicorns: Technology Capital and the Urban Politics of San Francisco. *Urban Geography* 37.4 (2016).

McQuire, S. 2019. Virilio, the'Infra'Urban and the Logic of Big Data. *Media Theory*, *3*(2).

McQuire, S. 2019b. One map to rule them all? Google Maps as digital technical object. *Communication and the Public*, 4(2).

Mei, J., Gao, B., Xu, D., Yao, W., Zhao, X. and Zhao, H. 2019. Semantic segmentation of 3d lidar data in dynamic scene using semi-supervised learning. *IEEE Transactions on Intelligent Transportation Systems*, *21*(6).

Merriman, P., 2012. Human geography without time□space 1. *Transactions of the institute of British Geographers*, *37*(1).

Metz, C. 1977. *The Imaginary Signifier. Psychoanalysis and the Cinema.* Indiana University Press.

Metz, D. 2018. "Developing Policy for Urban Autonomous Vehicles: Impact on Congestion" *Urban Science* 2, no. 2: 33.

Mezzadra, S. and Nielson, B. 2013. *Border as Method, or, The Multiplication of Labour*. Duke University Press.

Miller, J. 2017. Mediatization of the automobile. *Dynamics of Mediatization: Institutional Change and Everyday Transformations in a Digital Age.* (Driessens, O. et al. eds.). Springer.

Mills, C. and Pawson, K. 2012. Integrating motivation, risk-taking and self-identity: A typology of ICT enterprise development narratives. *International Small Business Journal*, 30(5).

Mills, S. 2013. Cultural–historical geographies of the archive: fragments, objects and ghosts. *Geography compass*, *7*(10).

Mills, T. 2018. What has become of critique? Reassembling sociology after Latour. *The British journal of sociology*, *69*(2).

Mitchell, W. J. T. 2005. *What Do Pictures Want?*. University of Chicago Press.

Mladenović, M. N. 2019. How Should We Drive Self-driving Vehicles? Anticipation and Collective Imagination in Planning Mobility Futures. *The Governance of Smart Transportation Systems*. (Finger, M. and Audouin, M. eds.). Springer.

Modelski, A. 1984. *Railroad Maps of North America: The First Hundred Years.* United States Govt Printing Office.

Mohl, R. 1981. Cognitive space in the interactive movie map: An investigation of spatial learning in virtual environments. PhD dissertation, Massachusetts Institute of Technology, Cambridge, MA.

Mom, G. 2014. *Atlantic Automobilism***:** *Emergence and Persistence of the Car, 1895-1940***.** Berghahn Books.

Monahan, T. 2018. The image of the smart city: Surveillance protocols and social inequality. *Handbook of cultural Security*, *210*. (Watanabe, Y. ed.). Edward Elgar Publishing.

Monmonier, M. 1993. *Mapping It Out: Expository Cartography for the Humanities and Social Sciences*. The University of Chicago Press.

Monmonier, M. 1996. *How To Lie With Maps*, *Second Edition.* University of Chicago Press.

Montani, P. 2019. *I formalisti russi nel cinema*. Mimesis.

Moore, B.E., Ali, S., Mehran, R. and Shah, M. 2011. Visual crowd surveillance through a hydrodynamics lens. *Communications of the ACM*, *54*(12).

Moravec, H. and Elfes, A.1985. High resolution maps from wide angle sonar. In *Proceedings. 1985 IEEE international conference on robotics and automation* (Vol. 2). IEEE.

Morente, F. and Ferràs, X. 2018. Open perseverance: the sensemaking narrative of startup entrepreneurs. *Journal of Business, Universidad del Pacífico (Lima, Peru)*, *10*(2).

Morin, E. 1992. From the concept of system to the paradigm of complexity. *Journal of social and evolutionary systems*, *15*(4).

Morin, E. 1999. Organization and complexity. *Annals of the New York Academy of Sciences*, *879*(1).

Muehlenhaus, I. 2012. If looks could kill: The impact of different rhetorical styles on persuasive geocommunication. *The Cartographic Journal*, 49(4).

Muehlenhaus, I. 2013. The design and composition of persuasive maps. *Cartography and Geographic Information Systems*, 40(5).

Mulvey, L. 2006. *Death 24x a second: Stillness and the moving image*. Reaktion Books.

Musich, J. 2006. Mapping a transcontinental nation: Nineteenth and early twentieth-century American rail travel cartography. *Cartographies of Travel and Navigation*. Akerman J R (ed.) Chicago University Press.

Mustikovela, S.K., Yang, M.Y. and Rother, C. 2016. Can ground truth label propagation from video help semantic segmentation? *European Conference on Computer Vision*. Springer International Publishing.

Mutlu, C.E. 2015. Of Algorithms. Data and Ethics: A Response to Andrew Bennett. *Millennium Journal of International Studies*, 43(3).

Myllylä, R., Marszalec, J., Kostamovaara, J., Mäntyniemi, A. and Ulbrich, G.J. 1998. Imaging distance measurements using TOF lidar. *Journal of optics*, *29*(3).

Naik, N., Kominers, S.D., Raskar, R., Glaeser, E.L. and Hidalgo, C.A. 2017. Computer vision uncovers predictors of physical urban change. *Proceedings of the National Academy of Sciences* 114(29).

Nederveen Pieterse, J. and Nederveen Pieterse, J., 2021. Technology and Connectivity. *Connectivity and Global Studies*. (Nerderveen Pieterse, J. ed.). Springer Nature.

Newell, R. and Canessa, R. 2015. Seeing, Believing, and Feeling: The Relationship between Sense of Place and Geovisualization Research. *Spaces & Flows: An International Journal of Urban & Extra Urban Studies*, *6*(4).

Nishiyama, H., 2018. Crowd surveillance: The (in) securitization of the urban body. *Security Dialogue*, *49*(3).

Noble, S. U. 2018. *Algorithms of oppression: How Search Engines Reinforce Racism*. NYU Press.

Novotny, L. 2007. The history of near-field optics. *Progress in optics*, *50*.

Novotny, L. 2011. From near-field optics to optical antennas. *Physics today*, *64*(7).

Nugent, D. and Suhail, A. 2021. Crisis, disorder and management: Smart cities and contemporary urban inequality. *Urban inequalities: Ethnographically informed reflections*.(Pardo, I., Prato, G. eds.). Palgrave Macmillan.

Nuchter, A., Surmann, H., Lingemann, K., Hertzberg, J. and Thrun, S. 2004. 6D SLAM with an application in autonomous mine mapping. In *IEEE International Conference on Robotics and Automation, 2004. Proceedings. ICRA'04. 2004* (Vol. 2). IEEE.

Olsson, G. 1991. *Lines of Power-Limits of Language*. University of Minnesota Press.

Olsson, G. 1998. Towards a critique of cartographical reason. *Ethics, Place and Environment*, *1*(2).

Olsson, G. 2007. *Abysmal: a critique of cartographic reason.* University of Chicago Press.

O'neil, C. 2017. *Weapons of math destruction: How big data increases inequality and threatens democracy*. Crown.

Ohnsman, A. 2017. Silicon Valley LiDAR Maker Quanergy Angles For A Trump Border Wall Contract https://www.forbes.com/sites/alanohnsman/2017/03/24/silicon-valley-lidar-maker-quanergy-angling-for-a-trump-border-wall-contract/ last accessed 8/5/23.

Othman, K. 2021. Public acceptance and perception of autonomous vehicles: a comprehensive review. *AI and Ethics*, *1*(3).

Padmaja, B., Moorthy, C.V., Venkateswarulu, N. and Bala, M.M., 2023. Exploration of issues, challenges and latest developments in autonomous cars. *Journal of Big Data*, *10*(1).

Palmini, O. and Cugurullo, F. 2023. Charting AI urbanism: conceptual sources and spatial implications of urban artificial intelligence. *Discover Artificial Intelligence*, *3*(1).

Parikka, J. 2023. *Operational Images: from the Visual to the Invisual*. MIT Press.

Parisi, L. 2013. *Contagious Architecture: Computation, Aesthetics, and Space*. MIT Press.

Parisi, L. 2021. Interactive Computation and Artificial Epistemologies. *Theory, Culture & Society*, *38*(7-8).

Parisi, L. 2021b. Negative optics in vision machines. *AI & Soc* 36.

Parks, L., and Starosielski, N. 2015. Introduction. In: L. Parks, and N. Starosielski, ed. *Signal traffic: Critical studies of media infrastructures*. University of Illinois Press.

Pasquale, F. 2015. *The black box society: The secret algorithms that control money and information*. Harvard University Press.

Parker, S. 2015. *Urban Theory and the Urban Experience*. Routledge.

Parks, L. 2014. Media, Hot & Cold| Drones, Infrared Imagery, and Body Heat. *International Journal of Communication*, *8*.

Pauwels, L. 2005. Websites as visual and multimodal cultural expressions: opportunities and issues of online hybrid media research. *Media Cult Soc* 27(4).

Pauwels, L. 2012. A multimodal framework for analyzing websites as cultural expressions. *Journal of Computer-Mediated Communication*, *17*(3).

Perkins, C. 2003. Cartography: mapping theory. *Progress in Human Geography*, *27*(3).

Perniola, M. 2017. *The Sex-Appeal of the Inorganic*. Bloomsbury.

Peterson, M.P. 1995. *Interactive and animated cartography*. Prentice Hall.

Pettersson, M. 2011. Depictive traces: On the phenomenology of photography. *Journal of Aesthetics & Art Criticism* 69 (2).

Pickles, J. (ed.) 1995. *Ground truth: The social implications of geographic information systems*. Guilford Press.

Pickles, J. 2012. *A history of spaces: Cartographic reason, mapping and the geo-coded world*. Routledge.

Picon, A. 2018. Urban infrastructure, imagination and politics: from the networked metropolis to the smart city. *International Journal of Urban and Regional Research*, *42*(2).

Pike, A. 2009. Geographies of brands and branding. *Progress in Human Geography*, *33*(5).

Plantin, J.C., Lagoze, C., Edwards, P.N. and Sandvig, C., 2018. Infrastructure studies meet platform studies in the age of Google and Facebook. *New media & society*, *20*(1).

Plantin, J.C. and Punathambekar, A. 2019. Digital media infrastructures: pipes, platforms, and politics. *Media, culture & society*, *41*(2).

Porcar, M., 2019. The Hidden Charm of Life. *Life*, *9*(1).

Poulsgaard, K.S. and Malafouris, L. 2020. Understanding the hermeneutics of digital materiality in contemporary architectural modelling: a material engagement perspective. *AI & SOCIETY*.

Power, M.J., Neville, P. and Devereux, E. 2012. Why bother seeing the world for real? Google Street View and the representation of a stigmatised neighbourhood. *New Media & Society*.

Pulikkaseril, C. and Lam, S. 2019. Laser eyes for driverless cars: the road to automotive LIDAR. In *2019 Optical Fiber Communications Conference and Exhibition (OFC)*. IEEE.

Pulvertaft, D., 2011. *Figureheads of the Royal Navy*. Pen and Sword.

Quinn, S.D. and MacEachren, A.M. 2018. A geovisual analytics exploration of the OpenStreetMap crowd. *Cartography and Geographic Information Science*, *45*(2).

Radcliffe, S. A. 2017. Geography and indigeneity I: Indigeneity, coloniality and knowledge. *Progress in Human Geography*, *41*(2).

Rana, M. M. and Hossain, K. (2023). Connected and autonomous vehicles and infrastructures: A literature review. *International Journal of Pavement Research and Technology*, *16*(2).

Rappaport, S. D. 2007. Lessons from Online Practice: New Advertising Models. Journal of Advertising Research, 47(2).

Richter, E., Lindner, P., Wanielik, G., Takagi, K. and Isogai, A. 2009. Advanced occupancy grid techniques for lidar based object detection and tracking. In *2009 12th International IEEE Conference on Intelligent Transportation Systems*. IEEE.

de Ridder, J., 2013. Is there epistemic justification for secrecy in science?. *Episteme*, *10*(2).

Rivera, G., Porras, R., Florencia, R. and Sánchez-Solís, J.P. 2023. LiDAR applications in precision agriculture for cultivating crops: a review of recent advances. *Computers and Electronics in Agriculture*, *207*.

Roberts, B. and Goodall, M. (eds.) 2019. *New media archaeologies*. Amsterdam University Press.

Roberts, E. 2013. Geography and the visual image: A hauntological approach. *Progress in Human Geography*, *37*(3).

Robinson, A. 1952. *The Look of Maps.* University of Wisconsin Press.

Rogers, E.M., Takegami, S. and Yin, J. 2001. Lessons learned about technology transfer. *Technovation*, *21*(4).

Roth, R.E., Çöltekin, A., Delazari, L., Filho, H.F., Griffin, A., Hall, A., Korpi, J., Lokka, I., Mendonça, A., Ooms, K. and van Elzakker, C.P. 2017. User studies in cartography: opportunities for empirical research on interactive maps and visualizations. *International Journal of Cartography*, *3*(sup1).

Rowe, F. 2021. Big Data and Human Geography. *Concise Encyclopedia of Human* Geography. (Demeritt, D. and Lees, L. eds.). Elgar Encyclopedias in the Social Sciences series

Rahman, S. A., Tuckerman, L., Vorley, T., & Gherhes, C. 2021. Resilient Research in the Field: Insights and Lessons From Adapting Qualitative Research Projects During the COVID-19 Pandemic. *International Journal of Qualitative Methods*, *20*.

Raj, T., Hanim Hashim, F., Baseri Huddin, A., Ibrahim, M.F. and Hussain, A. 2020. A survey on LiDAR scanning mechanisms. *Electronics*, *9*(5).

Rancière, J. 2000. *La partage du sensible: esthétique et politique*. La fabrique éditions.

Rancière, J. 2001. *La fable cinématographique*. Editions du Seuil.

Rancière, J. 2008. *Le spectateur émancipé*. La fabrique éditions.

Rancière, J. 2009. The aesthetic dimension: Aesthetics, politics, knowledge. *Critical Inquiry*, *36*(1).

Rangwala, S. 2021a. Smart Cities: is Lidar making them smarter? https://www.forbes.com/sites/sabbirrangwala/2021/08/20/smart-citiesis-lidar-making-them-smarter/?sh=31021df51b18 Last accessed December 2022.

Rangwala, S. 2021b. How will Pure Play public Lidar companies user their money. https://www.forbes.com/sites/sabbirrangwala/2021/10/29/how-will-pure-play-public-lidar-companies-use-their-money/ Last accessed 5/3/2024.

Rangwala, S. 2023. Automotive Lidar still alive and kicking. https://www.forbes.com/sites/sabbirrangwala/2023/01/22/automotive-lidarstill-alive--kicking/?sh=45bc7fa2aa30 Last accessed December 2022.

Rappaport, S. D. 2007. Lessons from Online Practice: New Advertising Models. *Journal of Advertising Research*, 47(2), 135–141.

Retours. 2017. https://www.reuters.com/article/autos-selfdriving-idUSL2N1N112A last accessed 8/5/23. No longer available.

Revill, G. 2016. How is space made in sound? Spatial mediation, critical phenomenology and the political agency of sound. *Progress in Human Geography*, *40*(2).

Roberts, J. K., Pavlakis, A. E., and Richards, M. P. 2021. It's More Complicated Than It Seems: Virtual Qualitative Research in the COVID-19 Era. *International Journal of Qualitative Methods*, *20*.

Roberts, L. 2015. Navigating the 'archive city': Digital spatial humanities and archival film practice. *Convergence*, *21*(1).

Rosa, H. 2010. *Alienation and Acceleration: Towards a Critical Theory of Late-Modern Temporality*. Aarhus Universitetsforlag.

Rose, G. 2016. Rethinking the geographies of cultural 'objects' through digital technologies: Interface, network and friction. *Progress in Human Geography*, *40*(3), pp.334-351.

Rose, G. 2017. Posthuman agency in the digitally mediated city: Exteriorization, individuation, reinvention. *Annals of the American Association of Geographers*, *107*(4), pp.779-793.

Rose, G. 2022. Visual methodologies: An introduction to researching with visual materials. *Visual methodologies*.

Rose, G. and Tolia-Kelly, D.P. 2012. Visuality/materiality: Introducing a manifesto for practice. *Visuality/materiality: Images, objects and practices*, pp.1-11.

Rose, G. and Willis, A. 2019. Seeing the smart city on Twitter: Colour and the affective territories of becoming smart. *Environment and Planning D: Society and Space*, *37*(3).

Rosiek, J. L., Snyder, J., & Pratt, S. L. 2020. The New Materialisms and Indigenous Theories of Non-Human Agency: Making the Case for Respectful Anti-Colonial Engagement. *Qualitative Inquiry*, *26*(3-4).

Rottensteiner, F. and Briese, C. 2003. Automatic generation of building models from LIDAR data and the integration of aerial images. *ISPRS*, Vol. XXXIV, Dresden.

Rubidge, S., 2011. Nomadic diagrams: Choreographic topologies. *Choreographic Practices*, *1*(1).

Sabeur, Z. and Arbab-Zavar, B. 2022. Crowd behaviour understanding using computer vision and statistical mechanics principles. *Crowd Dynamics, Volume 3: Modeling and Social Applications in the Time of COVID-19*. (Bellomo, N. and Gibelli, L. eds.). Springer International Publishing.

Salerno, S. 2014). Il linguaggio pubblicitario tra persuasione e retorica. *Journal of Communic*ation, 2.

Salovaara, I. 2016. Participatory maps: Digital cartographies and the new ecology of journalism. *Digital Journalism*, *4*(7).

Salter, M. 2014. Toys for the boys? Drones, pleasure and popular culture in the militarisation of policing. *Critical Criminology*, *22*.

Schwanen, T. 2018. Towards decolonised knowledge about transport. *Palgrave Communications*, *4*(1).

Schivelbusch, W. 1986. *The railway journey: The industrialization and perception of time and space*. University of California Press.

Schroeder, Fred E. H. 1991. 'More "Small Things Forgotten": Domestic Electrical Plugs and Receptacles, 1881-1931. *Technology and Choice: Readings from Technology and Culture.* (Lafollette, M.C and Stine, J.K. eds.). University of Chicago Press.

Scott, L.M., 1994. Images in advertising: The need for a theory of visual rhetoric. *Journal of consumer research*, *21*(2).

Scott, J.F., 2016. *The scientific work of René Descartes: 1596-1650*. Routledge.

Seidel, R.W. 1983. Accelerating science: The postwar transformation of the Lawrence Radiation Laboratory. *Historical Studies in the Physical Sciences*, *13*(2).

Semple, J. 1993. *Bentham's Prison: A Study of the Panopticon Penitentiary: A Study of the Panopticon Penitentiary*. Clarendon Press.

Seo, S.A. 2019. Policing the open road: how cars transformed American freedom. Harward University Press.

de Seta, G. and Shchetvina, A. 2023. Imagining machine vision: Four visual registers from the Chinese AI industry. *AI & SOCIETY*.

Shapiro, A.E., 1973. Kinematic optics: A study of the wave theory of light in the seventeenth century. *Archive for history of exact sciences*, *11*(2/3).

Shapiro, A. 2018. Street-level: Google Street View's abstraction by datafication. *new media & society*, *20*(3).

Sharma, S. 2014. *In the meantime: Temporality and cultural politics*. Duke University Press.

Sheller, M., 2007. Bodies, cybercars and the mundane incorporation of automated mobilities. *Social & Cultural Geography*, *8*(2).

Shi, Q., Xu, Q., Xing, S., Lan, C. and Liang, J. 2011. A Vector Collection Method Based on LiDAR Point Cloud Data. In *2011 International Symposium on Image and Data Fusion*. IEEE.

Siegel, J., Pappas, G. 2023. Morals, ethics, and the technology capabilities and limitations of automated and self-driving vehicles. *AI & Soc* 38.

Silver, C. 1991. The racial origins of zoning: Southern cities from 1910–40. *Planning Perspective*, *6*(2).

Singh, S. and Saini, B.S. 2021. Autonomous cars: Recent developments, challenges, and possible solutions. *IOP Conference Series: Materials Science and Engineering* (Vol. 1022, No. 1). IOP Publishing.

Siricharoen, W.V. 2013. Infographics: the new communication tools in digital age. In *The international conference on e-technologies and business on the web (ebw2013)* (Vol. 169174).

Smith, G. 1984. The early laser years at Hughes Aircraft Company. *IEEE journal of quantum electronics*, *20*(6), pp.577-584.

Smolnicki, P.M. and Sołtys, J. 2016. Driverless mobility: The impact on metropolitan spatial structures. *Procedia engineering*, *161*, pp.2184-2190.

Sloterdijk, P. 2011. *Bubbles: Spheres Volume I: Microspherology*. Semiotext(e).

Sobel, D. 2004. Longitude: The true story of a lone genius who solved the greatest scientific problem of his time. *Academy of Management Learning and Education*, *3*.

Sourbati, M., and Behrendt, F. 2020. Smart mobility, age and datajustice. In *New Media & Society*, 23(6).

Srnicek, N. 2017. *Platform Capitalism*. Polity.

Some, E., Gondwe, G. and Rowe, E.W. 2019. Cybersecurity and driverless cars: In search for a normative way of safety. In *2019 Sixth International Conference on Internet of Things: Systems, Management and Security (IOTSMS)*. IEEE.

Sornborger, T., 2021. Move Over IPOs: Unicorn Direct Listings May Be the New Mythical Beasts in Town. *Fordham J. Corp. & Fin. L.*, *26*.

Stabile, G. 2007. Teoria della Visione come Teoria della Conoscenza, in *Dante e la filosofia della natura: percezioni, linguaggio, cosmologie*. Micrologus' library 20.

Stalder, F. 2001. Flows and Nodes: The Financial Markets as New Media Environment. *Convergence*, *7*(3).

Steffensen, M., Rogers, E.M. and Speakman, K. 2000. Spin-offs from research centers at a research university. *Journal of business venturing*, *15*(1).

Steinberg, M. 2021. From automobile capitalism to platformcapitalism: Toyotism as a prehistory of digital platforms. In *Organization Studies,* 0(0).

Stewart, K. and Breitwieser, S. 2019. SCOPE: A digital archives access interface. *Code4Lib Journal*, (43).

Steichen, E. 1996. "American Aerial Photography at the Front (and Excerpt)." In Edward Steichen. Selected Texts and Bibliography, edited by R. J.Gedrim, 71–75. New York: G.K. Hall & Co.

Steven, M.D., 1987. Ground truth an underview. *International Journal of Remote Sensing*, *8*(7).

Stiegler, B. 2002. The discrete image. *Echographies of Television: Filmed Interviews*. (Derrida, J. and Stiegler, B. eds.). Polity Press.

Stiegler, B. 2011. *The Decadence of Industrial Democracies*. Translated by D. Ross and S. Arnold. Polity.

Stilgoe, J. 2017. "Seeing like a Tesla: How Can We Anticipate Self-Driving Worlds?". In *Glocalism: Journal of Culture, Politics and Innovation* 3.

Stilgoe, J. 2018. Machine Learning, Social Learning and the Governance of Self-Driving Cars. In *Social Studies of Science* 48 (1).

Stone, M. 2016. *A field guide to digital color*. CRC Press.

Sundell, L., 2022. Cyber archeology: Reconstructing buildings with 3D graphics and VR technology. Available at: https://www.diva-portal.org/smash/get/diva2:1677807/FULLTEXT01.pdf Last accessed 5/3/2024.

Sutherland, T. 2018. Mapping the space of flows: considerations and consequences. *Time for mapping*. (Hind, S. et al. eds.). Manchester University Press.

Swan, M. 2015. Connected Car: Quantified Self becomes Quantified Car. *Journal of Sensor and Actuator Networks, 4(1).*

Synge, E.H. 1928. A suggsted method for extending the microscopic resolution into the ultramicroscopic region. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science*. 6 (35).

Taeihagh, A. and Lim, H.S.M. 2019. Governing autonomous vehicles: emerging responses for safety, liability, privacy, cybersecurity, and industry risks. *Transport reviews*, *39*(1).

Talbert, R. J. A. (2010) *Rome's World: The Peutinger Map Reconsidered*. Cambridge University Press.

Tara, R. (2022). How to Use the Laser Scanner in Your Pocket https://www.engineering.com/story/how-to-use-the-laser-scanner-in-your-pocket Last accessed 5/3/2024.

Taylor, C. 2004 *Modern Social Imaginaries.* Duke University Press

Taylor, T.S. 2019. *Introduction to laser science and engineering*. CRC Press.

Teppati Losè, L., Spreafico, A., Chiabrando, F. and Giulio Tonolo, F. 2022. Apple LiDAR Sensor for 3D Surveying: Tests and Results in the Cultural Heritage Domain. *Remote Sensing*, *14*(17).

Terranova, C. (2014). *Automotive Prosthetic: Technological Mediation and the Car in Conceptual Art*. University of Texas Press.

Thatcher, J,, Mahmoudi, D., O'Sullivan, D. 2016. Data colonialism: The digital frontier, everyday life, and accumulation by dispossession. *Environment and Planning D: Society and Space* 34(6).

Thompson, E.P. (1967) Time, work-discipline, and industrial capitalism. *Past and Present* 38.

Thrift, N. 1977. Time and theory in human geography: part II. *Progress in Human Geography*, *1*(3).

Thrift, N. 1996. *Spatial Formations*. Sage Publications.

Thrift, N. 2014. The "sentient" city and what it may portend. *Big Data & Society, 1(1).*

Thrift, N. and Pred, A. 1981. Time-geography: a new beginning. *Progress in Human Geography*, *5*(2).

Thrower, N.J. 1959. Animated cartography. *Professional Geographer*, 11 (6).

Thrun, S. and Montemerlo, M. 2006. The graph SLAM algorithm with applications to large-scale mapping of urban structures. *The International Journal of Robotics Research*, *25*(5-6).

Thrun, S., Montemerlo, M., Dahlkamp, H., Stavens, D., Aron, A., Diebel, J., Fong, P., Gale, J., Halpenny, M., Hoffmann, G. and Lau, K. 2006. Stanley: The robot that won the DARPA Grand Challenge. *Journal of field Robotics*, *23*(9).

Thrun, S. and Liu, Y., 2005. Multi-robot SLAM with sparse extended information filers. *Robotics Research. The Eleventh International Symposium: With 303 Figures*. Springer.

Thurlow, C. and Jaworski, A. 2003. Communicating a global reach: Inflight magazines as a globalizing genre in tourism. *Journal of Sociolinguistics* 7(4).

Thylstrup, N.B., Agostinho, D., Ring, A., D'Ignazio, C. and Veel, K. (eds.) 2021. *Uncertain archives: Critical keywords for big data*. MIT Press.

Torres, F. 2016. A secular acceleration: Theological foundations of the sociological concept "social acceleration". *Time & Society*, *25*(3).

Townes, C.H. 2002. *How the laser happened: adventures of a scientist*. Oxford University Press

Tremblay, S., Castiglione, S., Audet, L.-A., Desmarais, M., Horace, M., & Peláez, S. 2021. Conducting Qualitative Research to Respond to COVID-19 Challenges: Reflections for the Present and Beyond. *International Journal of Qualitative Methods*, *20.*

Tripathi, A.K. 2018. Technological mediation and sociocultural variability. *Postphenomenological methodologies: new ways in mediating techno-human relationships.* (Aagaard, Friis, Sorensen, Tafdrup and Hasse Eds.). Lexington Books.

Tucker, C. 2002. Testing and verification of the accuracy of 3D laser scanning data. In *Symposium on geospatial theory, Processing and Applications, Ottawa*.

Turk, C. 2018. Maps as foams and the rheology of digital spatial media: a conceptual framework for considering mapping projects as they change over time. *OGRAPHIC TEMPORALITIES*.

Turnbull, D. 2000. *Masons, tricksters and cartographers: Comparative studies in the sociology of scientific and indigenous knowledge*. Taylor & Francis.

Turnbull, D. 2008. What is cartographic rationality? *Metascience*, *17*(2).

Turnbull, J., Searle, A., Hartman Davies, O., Dodsworth, J., Chasseray-Peraldi, P., von Essen, E. and Anderson-Elliott, H. 2023. Digital ecologies: Materialities, encounters, governance. *Progress in Environmental Geography*, *2*(1-2).

Tussyadiah, I.; Zach, F.J.; Wang, J. 2017. Attitudes towards autonomous on demand mobility system: The case of self-driving taxi. *Information & communication* technologies in tourism, R. Schegg, B. Stangl (Eds.) Springer

Tuve, M.A., Johnson, E.A. and Wulf, O.R. 1935. A new experimental method for study of the upper atmosphere. *Terrestrial Magnetism and Atmospheric Electricity*, *40*(4).

Tyner, J.A. 1982. Persuasive cartography. *Journal of Geography*, *81*(4).

Tyner, J.A. 2014. *Principles of map design*. Guilford Publications.

Tyner, J.A. 2020. Maps as language/the language of maps. *Handbook of the changing world language map*. (Brunn, S., Kehrein, R., Adamu, A.U., Afrin, S., Baines, L., Nahar, G., Baker, J.R., Balentine, M.D. and Webster, G.R eds.). Springer.

Uotinen, J. 2010. Digital television and the machine that goes "PING!": Autoethnography as a method for cultural studies of technology. *Journal for Cultural Research*, *14*(2).

Valentine, D. 2016. Atmosphere: Context, detachment, and the view from above earth. *American Ethnologist* 43(3).

Valera, M. and Velastin, S.A., 2005. Intelligent distributed surveillance systems: a review. *IEE Proceedings-Vision, Image and Signal Processing*, *152*(2).

Van der Heijden, T. and Kolkowski, A. 2022. *Doing experimental media archaeology: Practice*. De Gruyter.

Van Dijick, J. 2014. Datafication, dataism and dataveillance: Big Data between scientific paradigm and ideology. In *Big Data and Society*, Vol 12 No 2.

Van Keuren, D.K. 1997. Science goes to war: The radiation laboratory, radar, and their technological consequences. *Reviews in American History*, *25*(4).

Van Rees, E. 2023. Luminar acquires HD Mapping Startup Civil Maps https://www.geoweeknews.com/news/luminar-acquires-hd-mapping-startup-civil-maps Last accessed 5/3/2023.

Vanolo, A. 2014. Smartmentality: The smart city as disciplinary strategy. *Urban studies*, *51*(5).

Verbeek, P.P. 2005. *What things do: philosophical reflections on technology, agency and design.* The Pennsylvania State University Press.

Verbeek, P.P. 2008. Cyborg intentionality: rethinking the phenomenology of human–technology relations. *Phenomenol Cognit Sci* 7.

Verity, E. 1980. *Colour Observed* . Palgrave.

Vertesi, J. 2012. Seeing like a Rover: Visualization, embodiment, and interaction on the Mars Exploration Rover Mission. *Social Studies of Science*, *42*(3).

Vertesi, J. 2015. *Seeing like a rover: How robots, teams, and images craft knowledge of Mars*. University of Chicago Press.

Vilnai-Yavetz, I. and Tifferet, S. 2009. Images in Academic Web Pages as Marketing Tools: Meeting the Challenge of Service Intangibility. *Journal of Relationship Marketing, 8(2).*

Virilio, P. 1994. *The Vision Machine*. Translated by Julie Rose. Indiana University Press.

Virilio, P. 2006. *Speed and Politics: An Essay on Dromology*. Translated by M. Polizzotti. Semiotext(e).

Vlassenroot, E., Chambers, S., Lieber, S., Michel, A., Geeraert, F., Pranger, J., Birkholz, J. and Mechant, P. 2021. Web-archiving and social media: an exploratory analysis: Call for papers digital humanities and web archives–A special issue of international journal of digital humanities. *International Journal of Digital Humanities*, *2*(1-3).

Voordijk, H. and olde Scholtenhuis, L. 2022. Technological mediation and 3D visualizations in construction engineering practice. *AI & SOCIETY*.

Voorveld, H.A., Neijens, P.C. and Smit, E.G., 2011. The relation between actual and perceived interactivity. *Journal of Advertising*, *40*(2).

Voorveld, H., van Noort, G. & Duijn, M. 2013. Building brands with interactivity: The role of prior brand usage in the relation between perceived website interactivity and brand responses. *J Brand Manag* 20.

Vukov, T. 2016. Target practice: The algorithmics and biopolitics of race in emerging smart border practices and technologies. *Transfers*, *6*(1).

Wakabayashi D. and Isaac M. 2017. Google self-driving car unit accuses Uber of using stolen technology. Available at: https://www.nytimes.com/2017/02/23/technology/google-self-driving-waymo-uber-otto-lawsuit.html Last accessed 6/3/2024.

Wandinger, U. 2005. Introduction to lidar. *Lidar: range-resolved optical remote sensing of the atmosphere*. Springer New York.

Wang, B.T. 2021. The Machine Metropolis: Introduction to the Automated City. *Automating Cities. Advances in 21st Century Human Settlements*. (Wang, B.T., Wang, C.M. eds.). Springer.

Warf, B., 2017. Fiber Optics: Nervous System of the Global Economy. *Handbook on Geographies of Technology*, *120*.

Warf, B. and Sui, D. 2010. From GIS to neogeography: ontological implications and theories of truth. *Annals of GIS*, 16:4.

Watts, M., Poulton, C., Byrd, M. and Smolka G. 2023. Lidar on a chip puts self-driving cars in the fast lane. Available at: https://spectrum.ieee.org/lidar-on-a-chip
Last accessed 6/3/2024.

Weale, S. 2022. Parents urge UK Universities to reveal student suicide rates. Available at: https://www.theguardian.com/education/2022/oct/05/parents-urge-uk-universities-to-reveal-student-suicide-rates
Last accessed 6/3/2024.

Weheliye, A.G. 2014. *Habeas viscus: Racializing assemblages, biopolitics, and black feminist theories of the human*. Duke University Press.

Weizman, E. 2017. *Forensic architecture: Violence at the threshold of detectability*. Princeton University Press.

Wellner, G. 2017. I-media-world. *Postphenomenology and media: Essays on human–media–world relations* (Van Den Eede, Y., Irwin, S.O.N. and Wellner, G eds.). Lexington Books.

Wellner, G. 2018. From cellphones to machine learning. a shift in the role of the user in algorithmic writing. *Towards a philosophy of digital media*. (Romele, A. and Enrico Terrone, E. eds.). Palgrave MacMillan.

Wellner, G. 2020. Material hermeneutic of digital technologies in the age of AI. *AI & SOCIETY* 25.

Weston, K. 2018. *Gender in real time: Power and transience in a visual age*. Routledge.

Wiener, N. 1948/2019. *Cybernetics or Control and Communication in the Animal and the Machine*. MIT press.

Wigley, E. and Rose, G. 2020. Who's behind the wheel? Visioning the future users and urban contexts of connected and autonomous vehicle technologies. In *Geografiska Annaler: Series B*, Human Geography, 102(2).

Wijermans, N., Conrado, C., van Steen, M., Martella, C. and Li, J., 2016. A landscape of crowd-management support: An integrative approach. *Safety science*, *86*.

Wijeyasinghe, N., 2019. The Lidar Revolution: Enabling Machines to See Our World. Available at: https://www.idtechex.com/de/research-article/the-lidar-revolution-enabling-machines-to-see-our-world/18522 Last accessed 14 September 2023.

Wilken, R. and Thomas, J. 2019. Maps and the autonomous vehicle as a communication platform. *International Journal of Communication*, 13.

Williams, A. and Srnicek, N. 2013. *# ACCELERATE MANIFESTO for an Accelerationist Politics*. Rhuthmos.

Willis, K. and Aurigi, A. 2017. *Digital and smart cities*. Routledge.

Wilmott, C. 2017. In-between mobile maps and media: Movement. *Television & New Media* 18(4).

Wilmott, C. 2020. *Mobile mapping: Space, cartography and the digital*. Amsterdam University Press.

Wilson, J. P. 2014. *Geographic Information Science & Technology*

Body of Knowledge 2.0 Project Final Report. University Consortium for Geographic Information

Science Symposium, Pasadena, California. Available at:

https://ucgis.memberclicks.net/assets/docs/ucgis_bok2_wilson_report_dec2014.pdf

Last accessed 6/3/2024.

Wilson, M.W. 2012. Location-based services, conspicuous mobility, and the location-aware future. *Geoforum*, *43*(6).

Wilson, M.W. 2017. *New lines: Critical GIS and the trouble of the map*. University of Minnesota Press.

Wiltse, H. 2014. Unpacking Digital Material Mediation. *Techné Res Philos Technol* 18(3).

Winter, M. and Tomko, S. 2019. Beyond digital twins – a commentary. In *Envir Plann B: Urb Anal City Sci* 46(2).

Wood, D. 2010. *Rethinking the Power of Maps.* Guilford Press.

Woolgar, S.(ed.). 2002. *Virtual Society? Technology, Cyberbole, Reality*. Oxford University Press

Xue, F., Lu, W., Chen, Z., & Webster, C. J. 2020. From LiDAR point cloud towards digital twin city: Clustering city objects based on Gestalt principles. *ISPRS Journal of Photogrammetry and Remote Sensing, 167.*

Yastikli, N. and Cetin, Z. 2016. Classification of LiDAR data with point based classification methods. *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, *41*.

Yeo, S. J. I. and Lin, W. 2020. Autonomous vehicles, human agency and the potential of urban life. *Geography Compass*, 14(10).

Youd, F. 2022. Sensing the surroundinga: Blickfeld's LiDAR technology. Available at: https://www.airport-technology.com/features/sensing-the-surroundings-blickfelds-lidar-technology/ Last accessed 6/3/2024.

Young, S. and Schwarz, B. 2010. LIDAR in the drivers seat. *Optics and Photonics*, *12*.

Yvkoff, L. 2020. The success of autonomous vehicles hinges on smart cities. Available at: https://www.forbes.com/sites/lianeyvkoff/2020/10/28/the-success-of-autonomous-vehicles-hinges-on-smart-cities-inrix-is-making-it-easier-to-build-them/?sh=28a4a2b2bfe6
Last accessed 2/12/2022.

Zhang, X., Yu, Q. and Yu, H. 2018. Physics inspired methods for crowd video surveillance and analysis: a survey. *IEEE Access*, *6*.

Zhangyu, W., Guizhen, Y., Xinkai, W., Haoran, L. and Da, L. 2021. A camera and LiDAR data fusion method for railway object detection. *IEEE Sensors Journal*, *21*(12).

Zollet, R. and Back A. 2015. Critical Factors Influencing Diffusion of Interactivity Innovations on Corporate Websites. *IEEE Transactions on Professional Communication*, vol. 58, no. 1.

Zook, M. 2017. Crowdsourcing the smart city: Using big geosocial media metrics in urban governance. *Big Data & Society*, 4(1).

Zook, M.A. and Blankenship, J. 2018. New spaces of disruption? The failures of Bitcoin and the rhetorical power of algorithmic governance. *Geoforum* 96.

Zook, M. and Graham, M. 2018. Hacking code/space: Confounding the code of global capitalism. *Transactions of the Institute of British Geographers* 40(3).

Zuboff, S. 2019. *The Age of Surveillance Capitalism: the Fight for a Human Future at the New Frontier of Power*. Public Affairs.

Appendix A

Appendix A

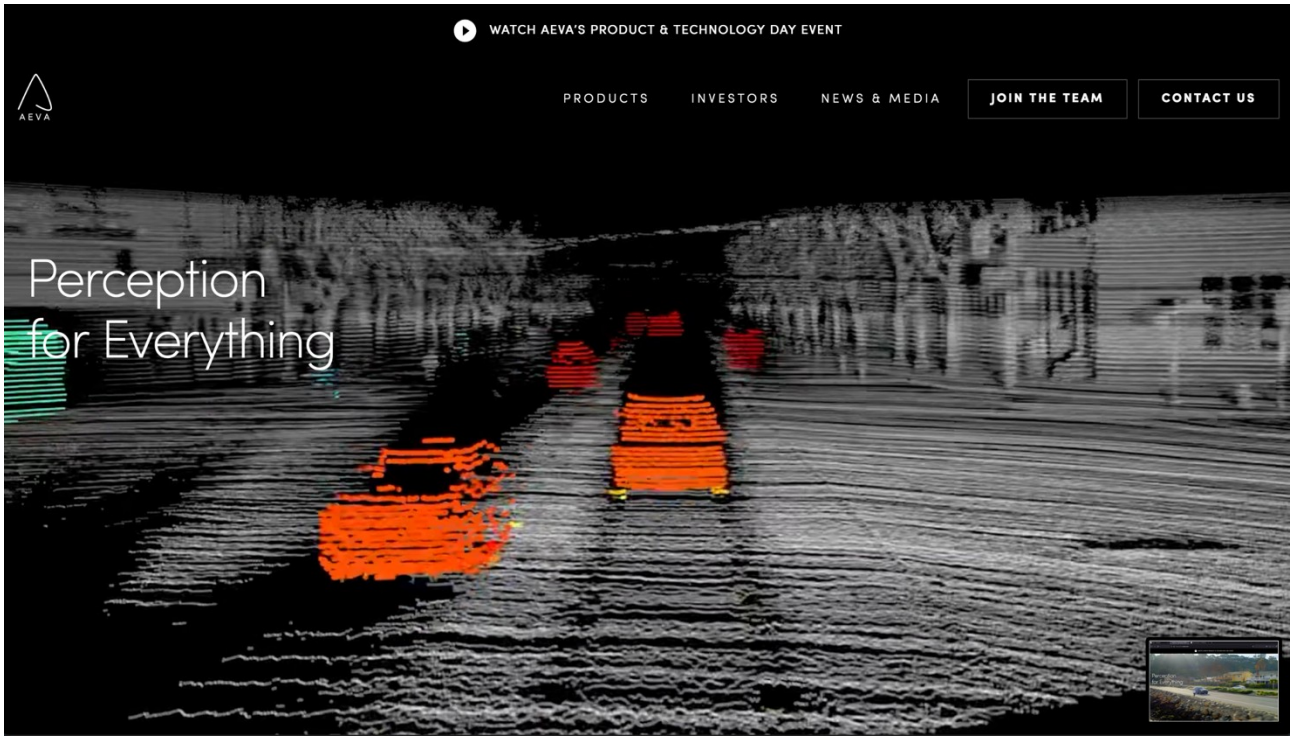
Prominence and significance of Lidar imagining online

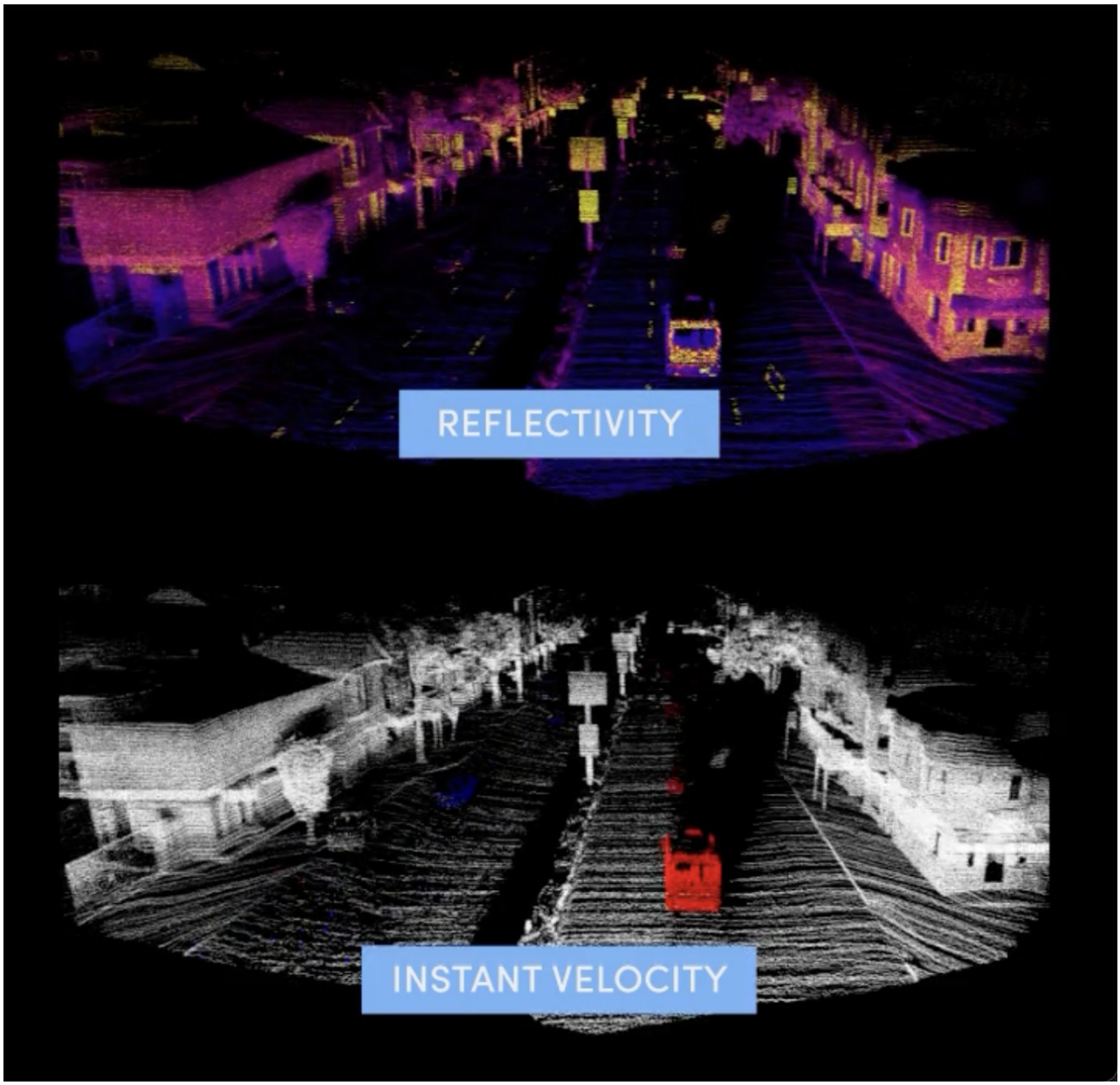
May 2022

At the time of the end of the survey (31/5/2022), website addresses were accurate and functioning, except were indicated with the expression “No website available”. On the contrary, “no images available” means that no form of geovisuality was showcased on the website.
In the case of animated maps (both in GIFs or videos), only representative shots were taken and included below.

1. Aeva (USA), <https://www.aeva.com/>

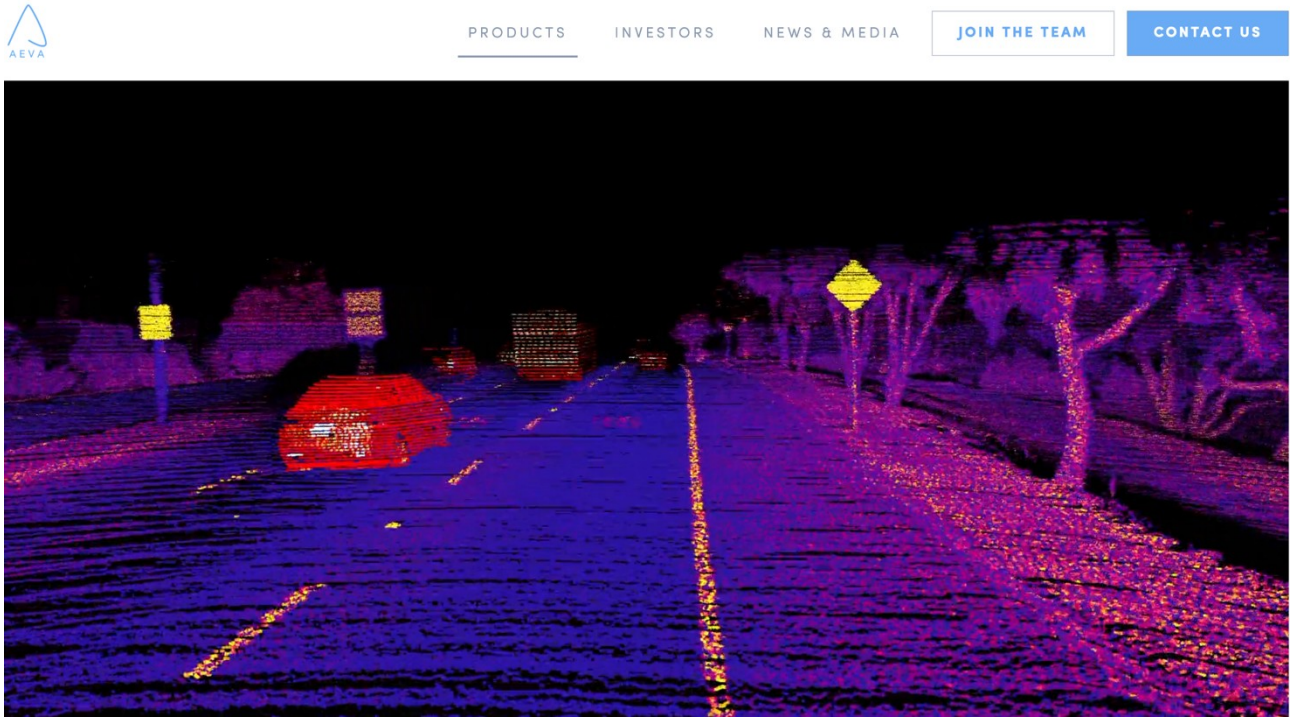
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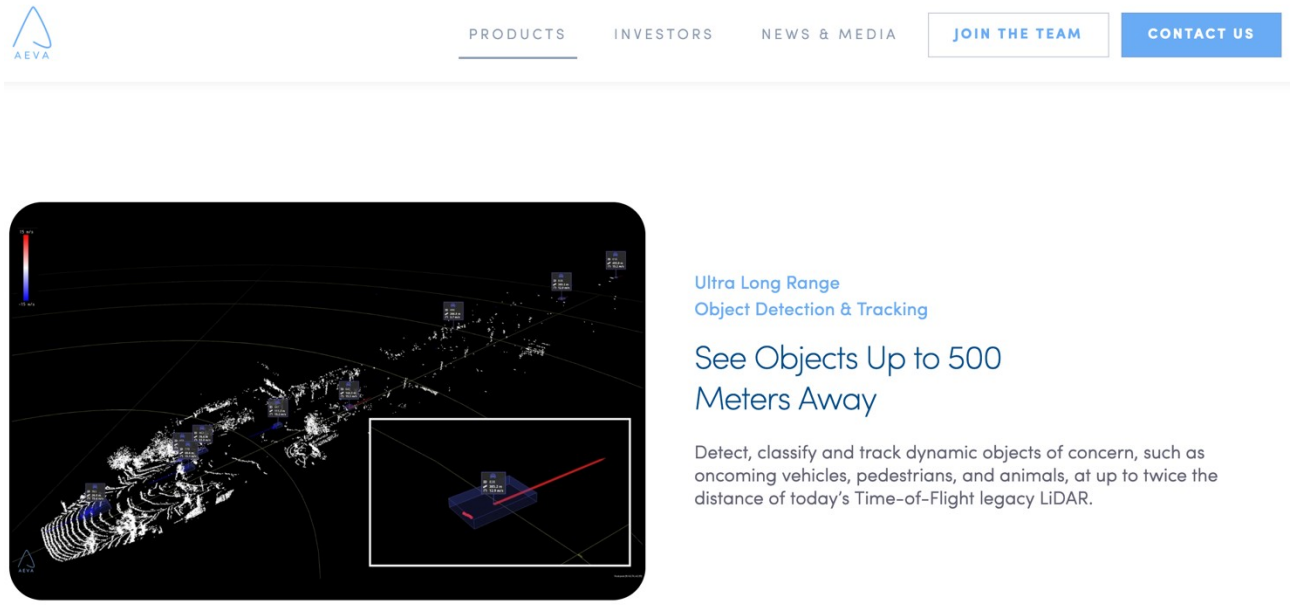




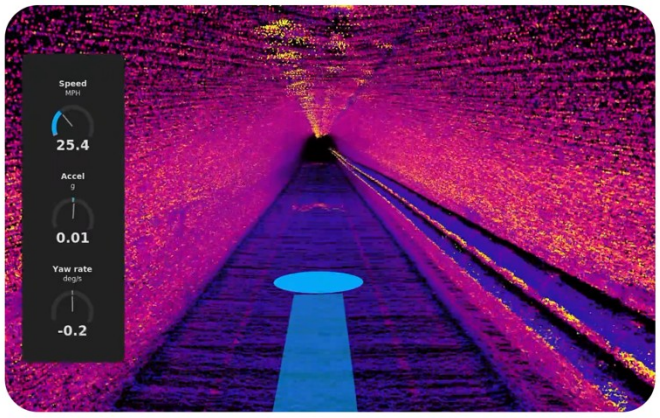
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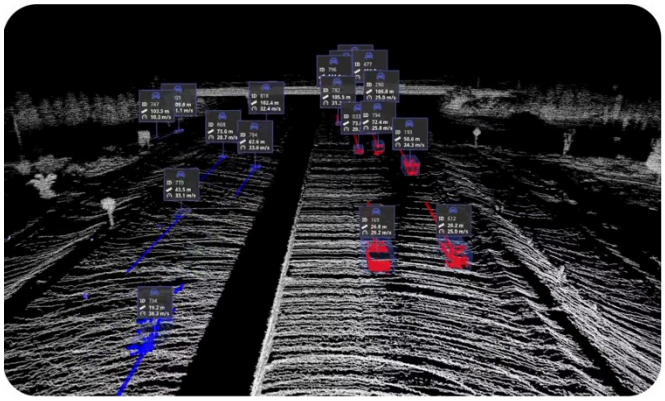

AEVA
PRODUCTS
INVESTORS
NEWS & MEDIA
JOIN THE TEAM
CONTACT US
DISTANCE
INSTANT VELOCITY
REFLECTIVITY
CAMERA


AEVA
PRODUCTS
INVESTORS
NEWS & MEDIA
JOIN THE TEAM
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Source: < https://www.aeva.com/aeries-ii/>





Object Detection & Classification

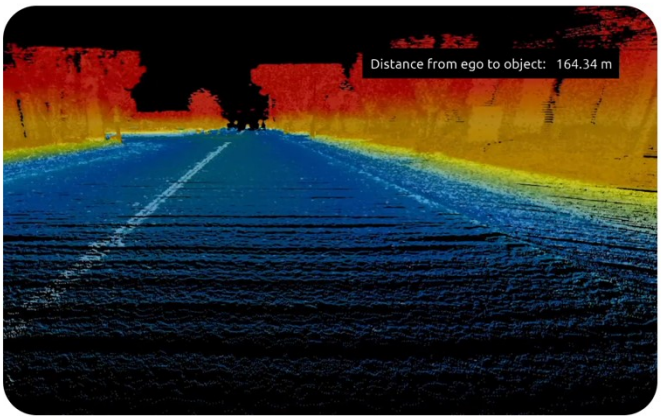
High Confidence Detection, Classification, & Tracking

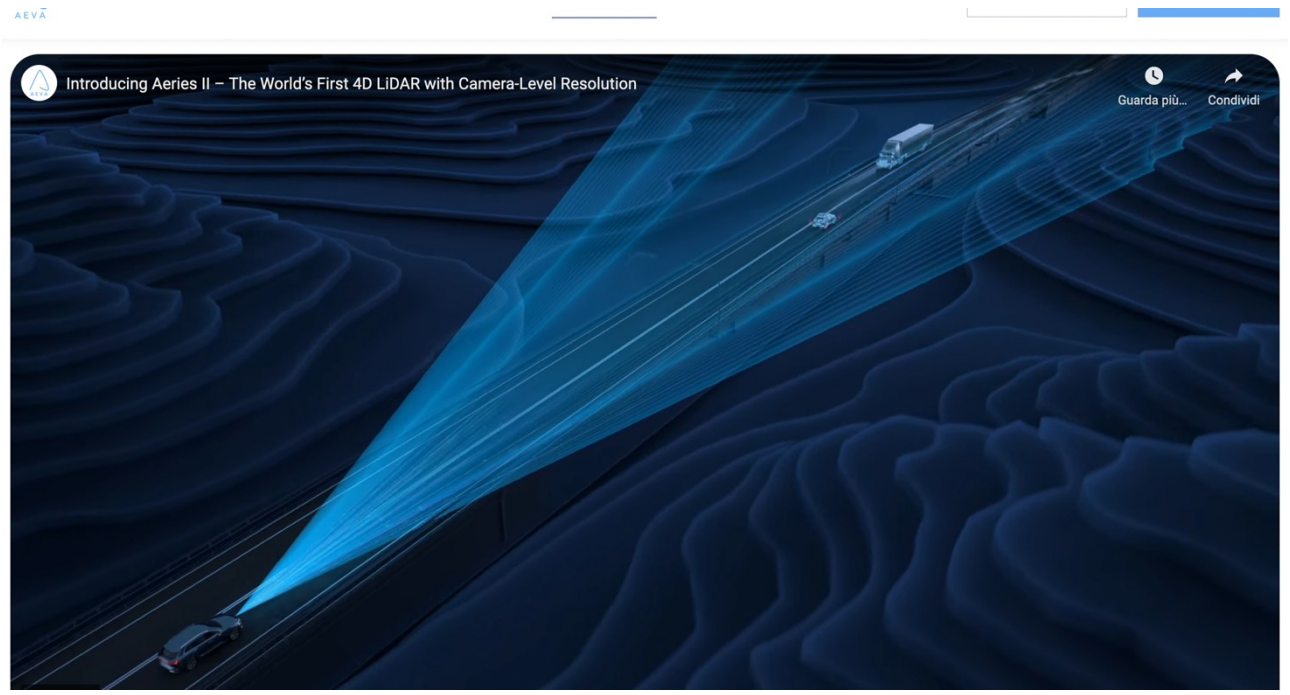
Instant velocity data allows for high confidence detection and tracking of dynamic objects of concern, such as oncoming vehicles and pedestrians, at distances up to 500 meters.

Superior Hazard Detection

Identify Small Objects with Greater Confidence

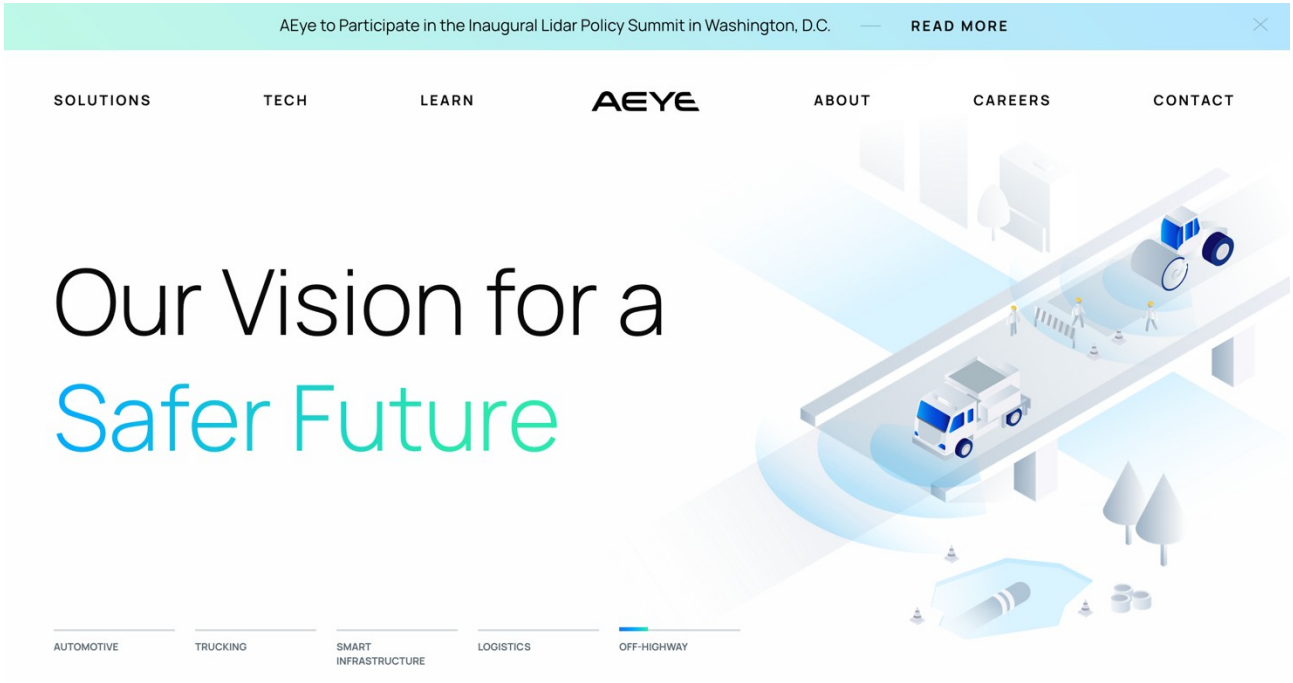
Detect small objects on the road, including low reflectivity objects like tire fragments, at up to twice the distance of legacy time of flight LiDAR sensors.



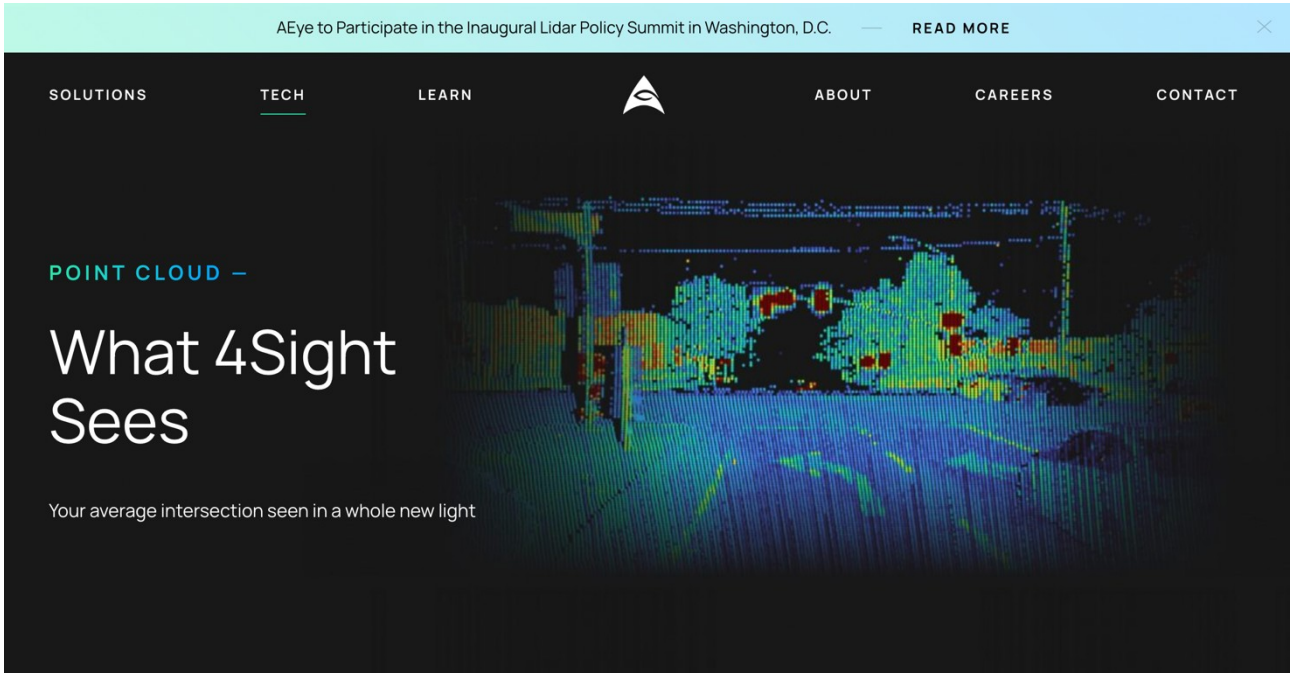


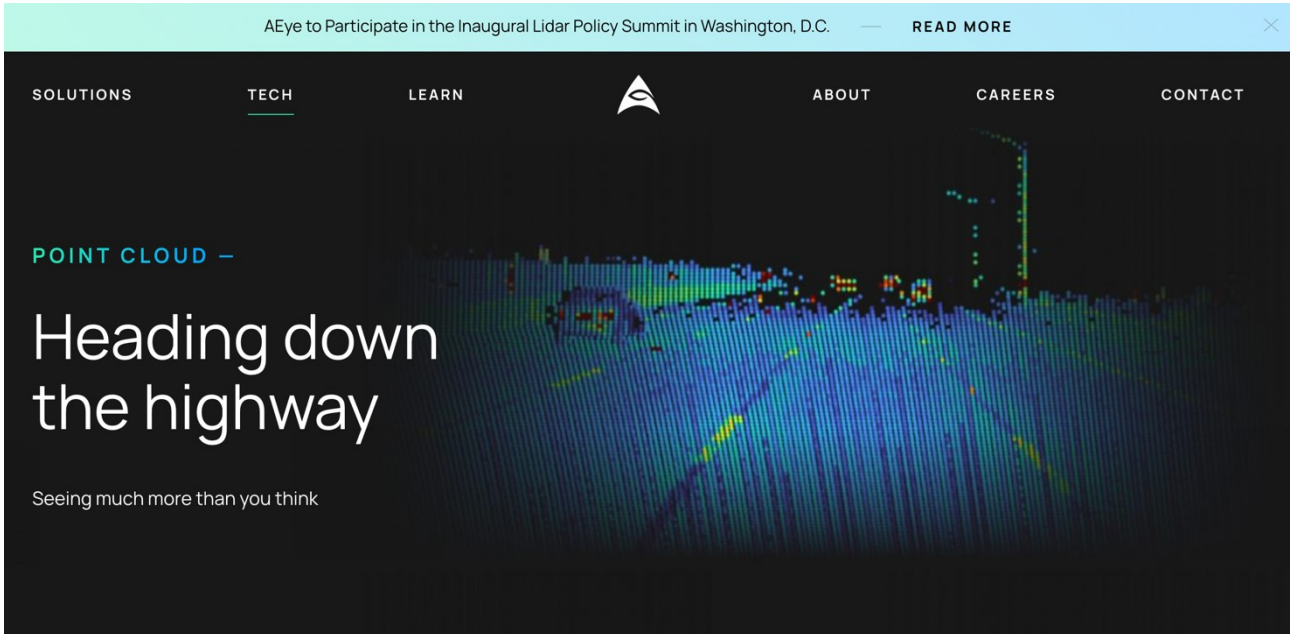
2. Aeye (USA), < https://www.aeye.ai/>

Source: <https://www.aeye.ai/>

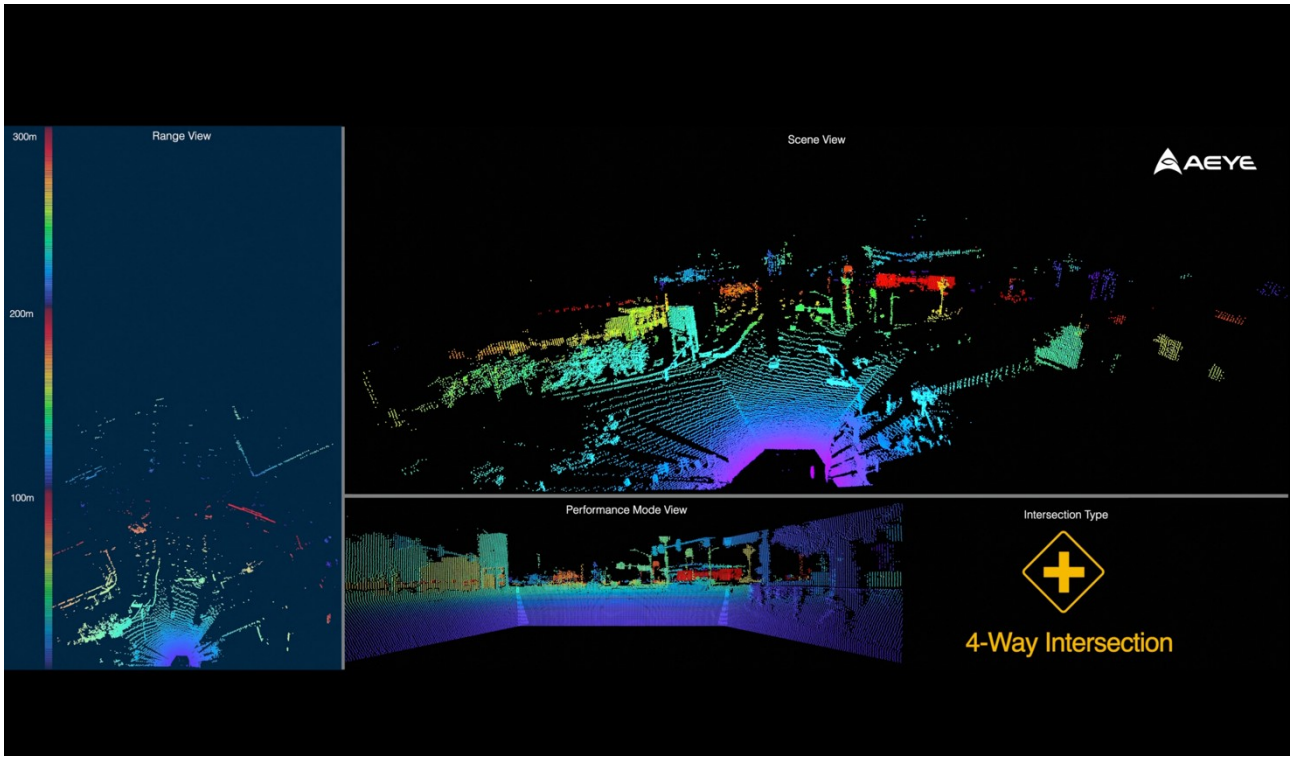


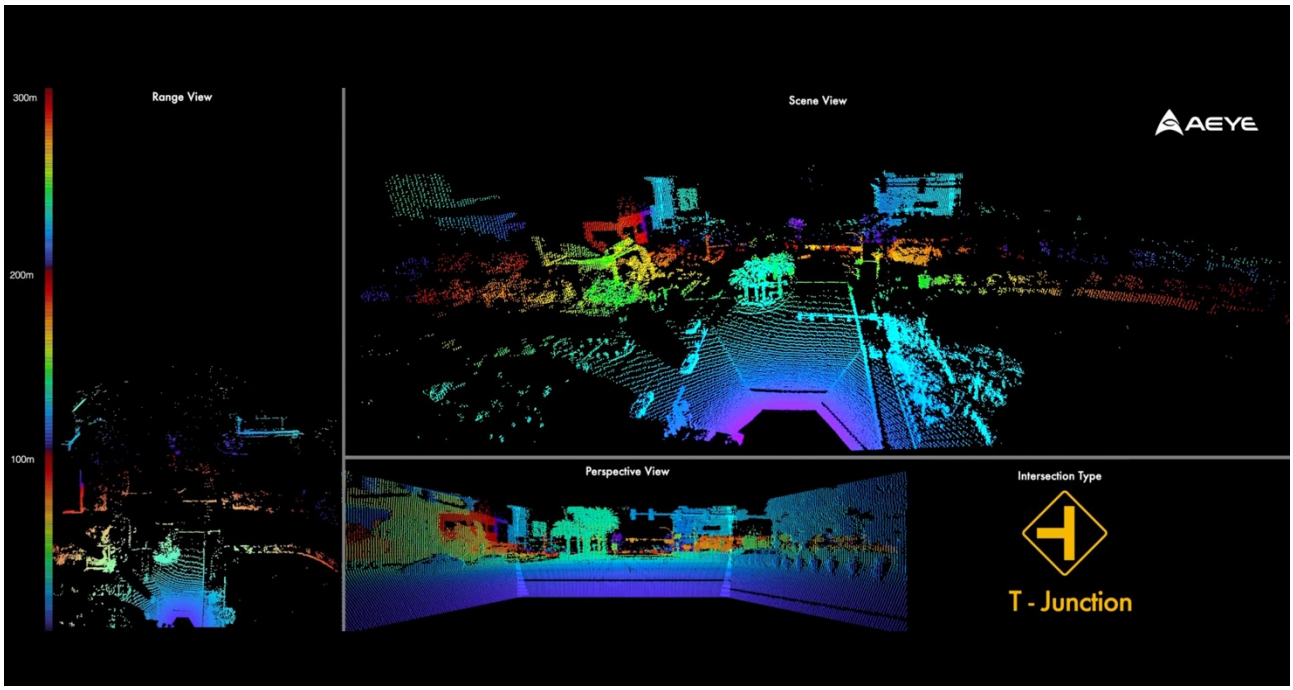
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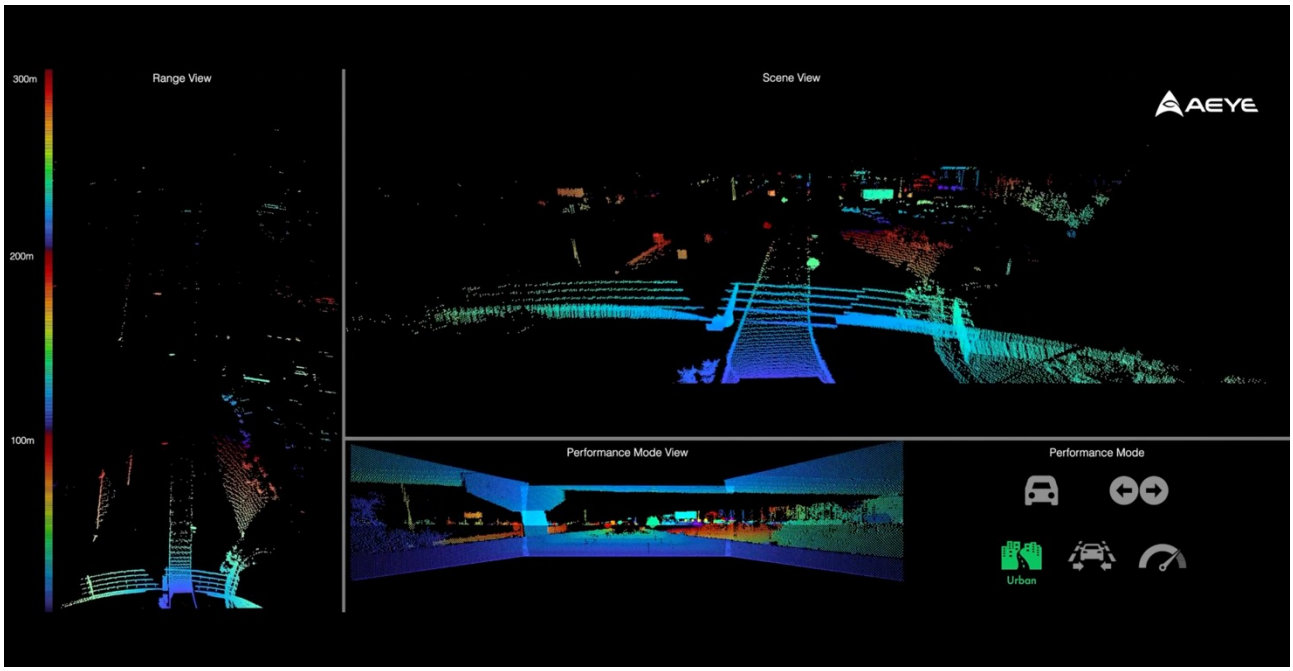


Source: < https://www.aeye.ai/resources/videos/virtual-intersection-demo-for-its-applications/>

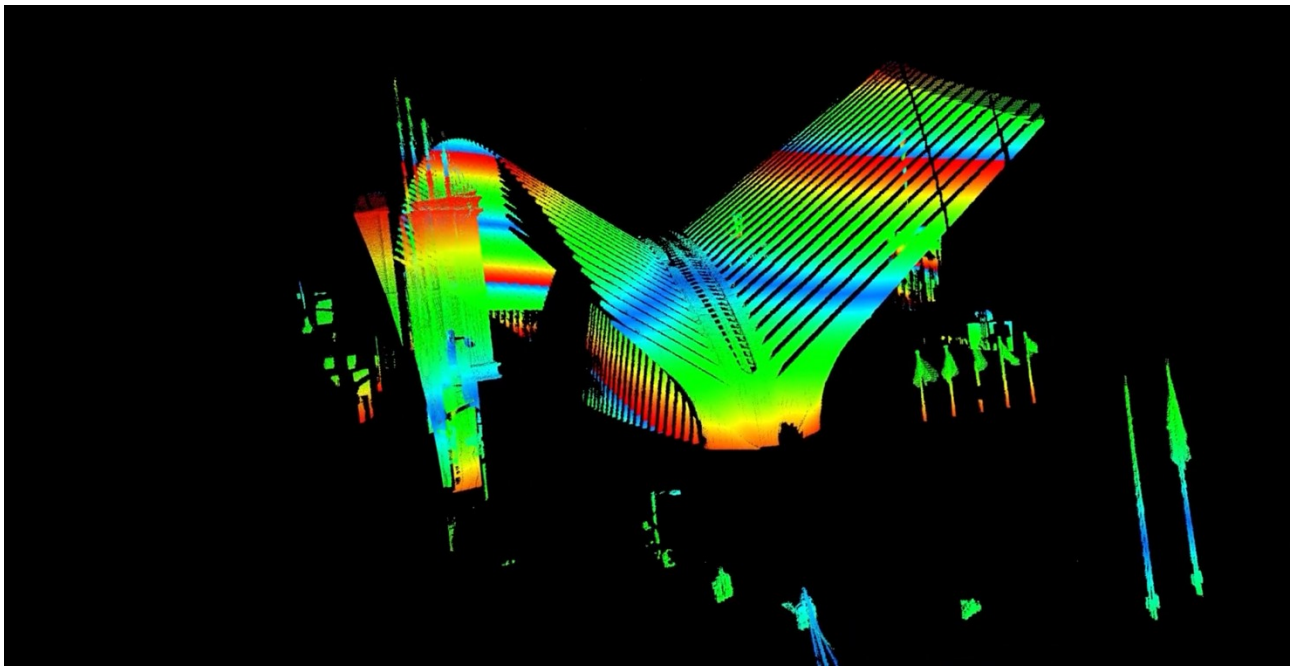




Source: < https://www.aeye.ai/resources/videos/virtual-driving-demo-for-automotive-applications/>



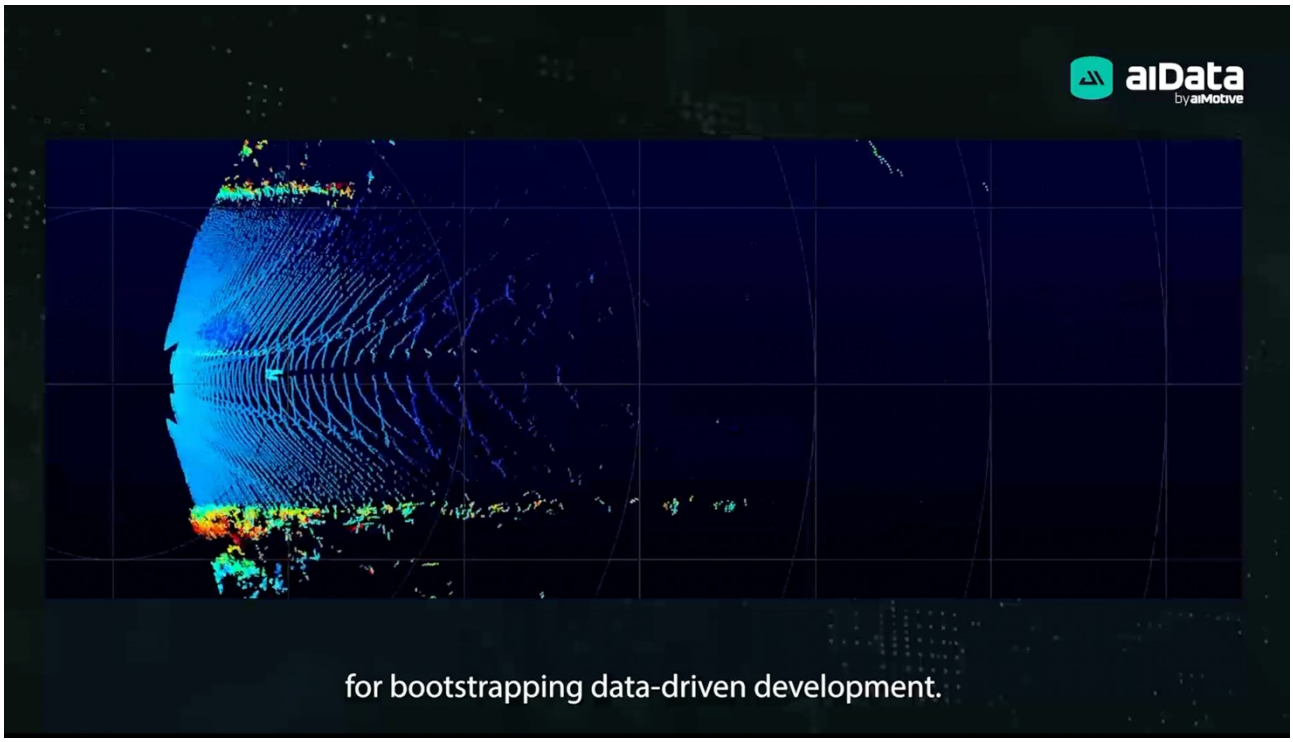
Source: < https://www.aeye.ai/resources/videos/project-point-cloud-new-york-city-compilation/>



3. Aimotive (Hungary), < https://aimotive.com/>

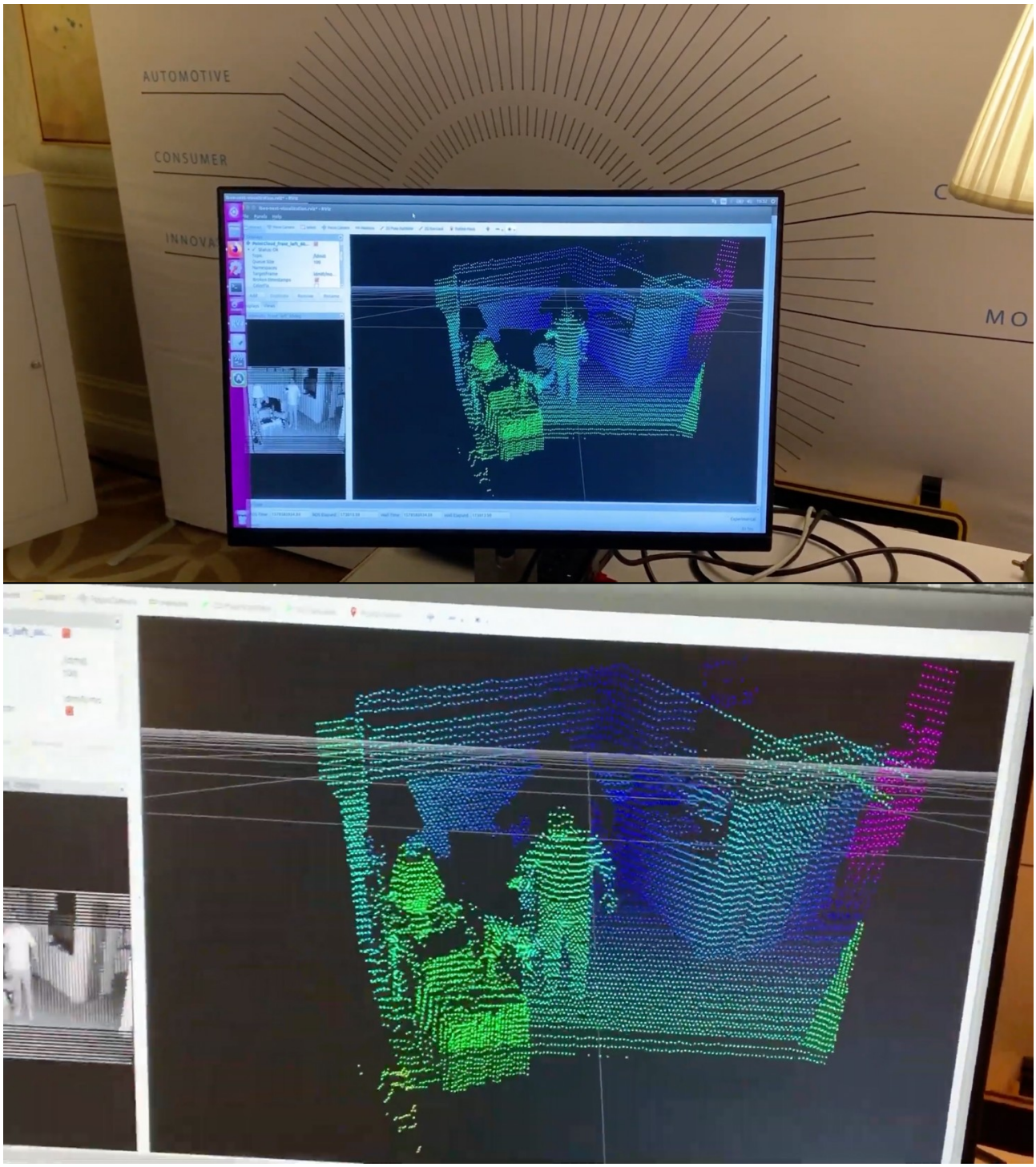
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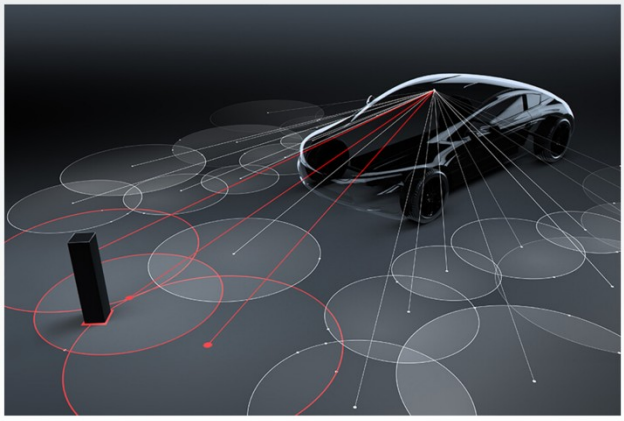


4. Ams (Austria), < https://ams.com/ams-start>

Source: < https://www.youtube.com/embed/5zknGuXNXwQ?rel=0&fs=1>



Source: < https://ams.com/lidar>



Flash vs. Scan

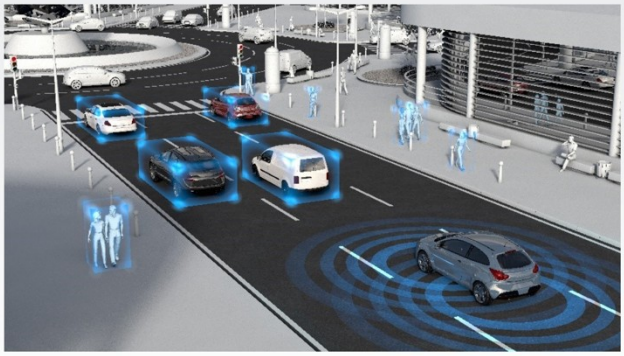
A LiDAR system can observe the complete field of view (FOV) at once, called Flash systems. Flash typically works well for short to mid-range (0-100m), and by capturing the complete scene at once also objects with high relative speeds can be detected properly. Another implementation is to focus on a subset of the FOV, consequentially look at the next subsets, until the complete FOV is covered, called Scanning. Scanning can focus the light on the subset instead of the full FOV, and therefore can do object detection at a longer range compared to Flash.

As a scanner only takes one subset of the FOV, it needs some steering principle to move the light beam from subset to subset. Current systems typically use a mechanical beam steering principle; either by rotating the complete sensor head (spinning LiDAR), or using mechanical components inside the sensor (Polygon mirrors, MEMS mirrors). More and more industry players acknowledge the risk these mechanical parts fail and therefore look for beam steering principles without any moving parts, or true solid state.

LiDAR & Direct Time of Flight

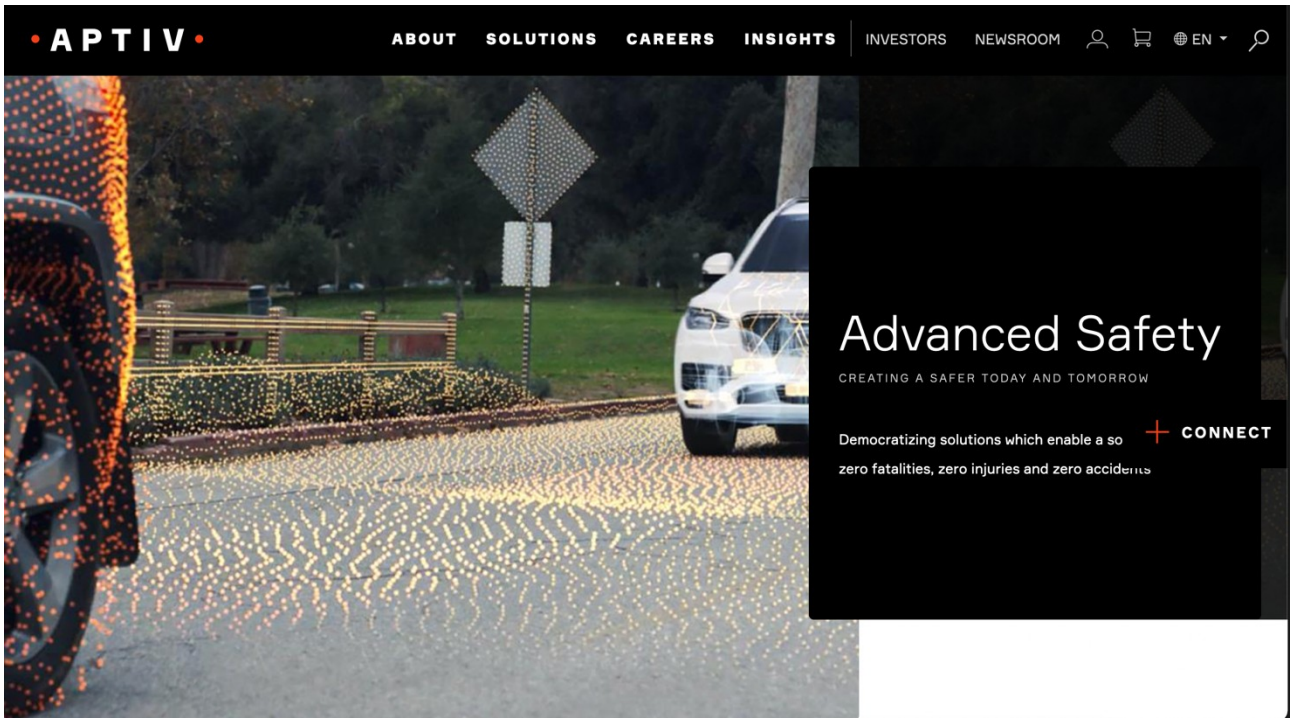
LiDAR (Light Detection and Ranging) is a sensor technology for remote object detection and ranging, using a light source and receiver. Emitted light pulses hit objects, reflect, and return to the LiDAR sensor system where the receiver detects the returning light pulse.
The time between sending and receiving a light pulse is dependent on the distance between the LiDAR system and the object. Knowing time allows you to calculate distance. The most straightforward implementation of this principle is Direct Time of Flight (D-ToF). The system emits short pulses of Near Infrared light. A portion of that energy is returned and converted in distance and optionally intensity and ultimately speed. By taking many samples, it is possible to filter out noise (detected light not being a reflection of the emitted pulse).

More about Time-of-Flight



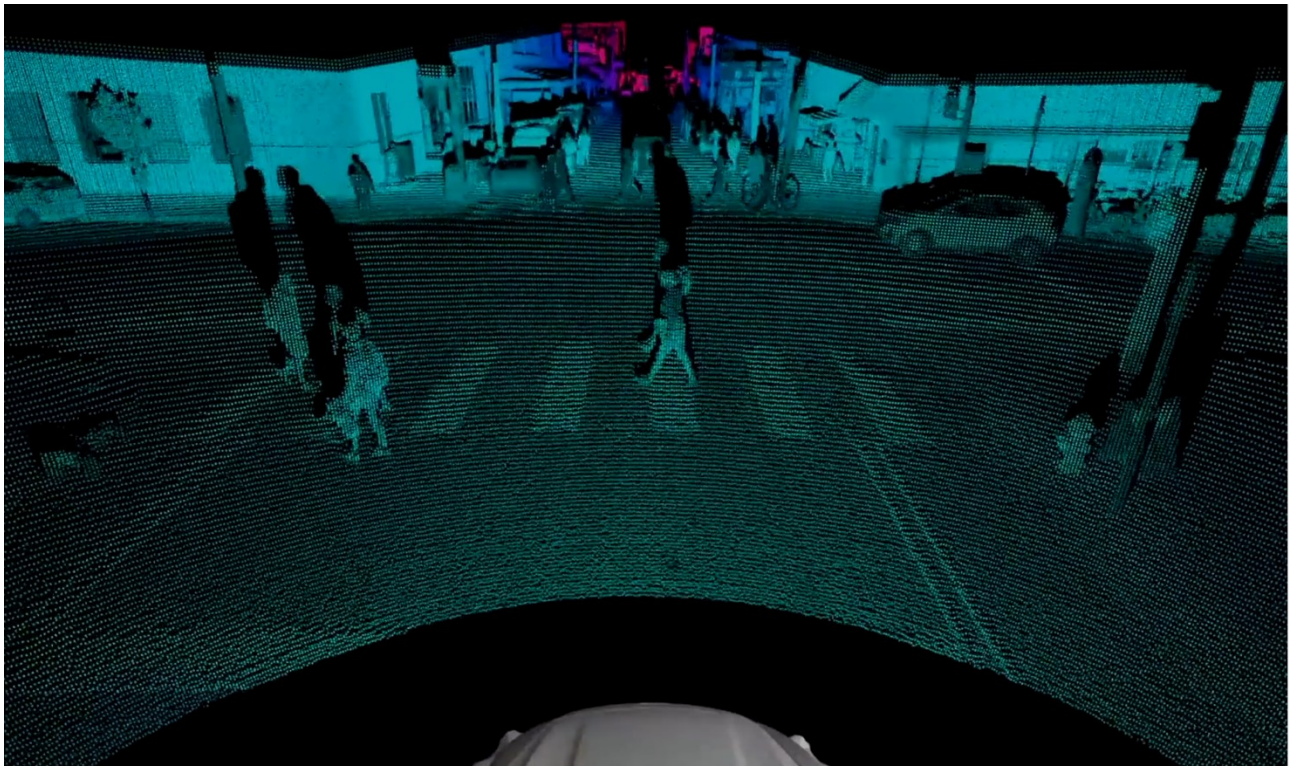
5. Aptiv (Ireland), < https://www.aptiv.com/en/>

Source: < https://www.aptiv.com/en/solutions/advanced-safety>



6. Argo.ai (USA) < https://www.argo.ai/>

Source: < https://www.argo.ai/>



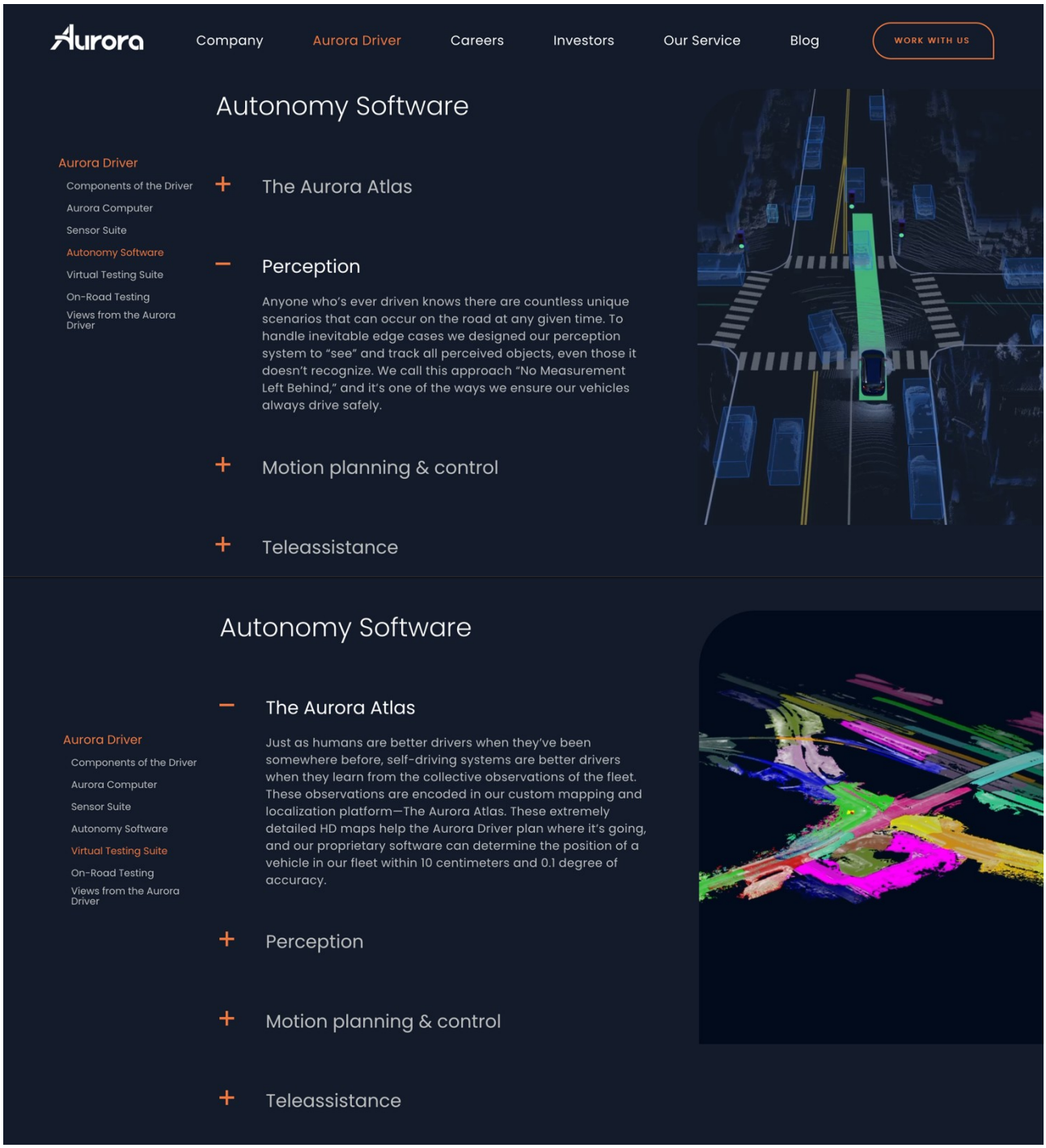
Source: < https://www.argo.ai/products/>


ARGO AI
AUTONOMOUS MODE
19
MPH
Pittsburgh, PA
2:30 PM EST
January 24, 2020
that detect people, cars, and other road users



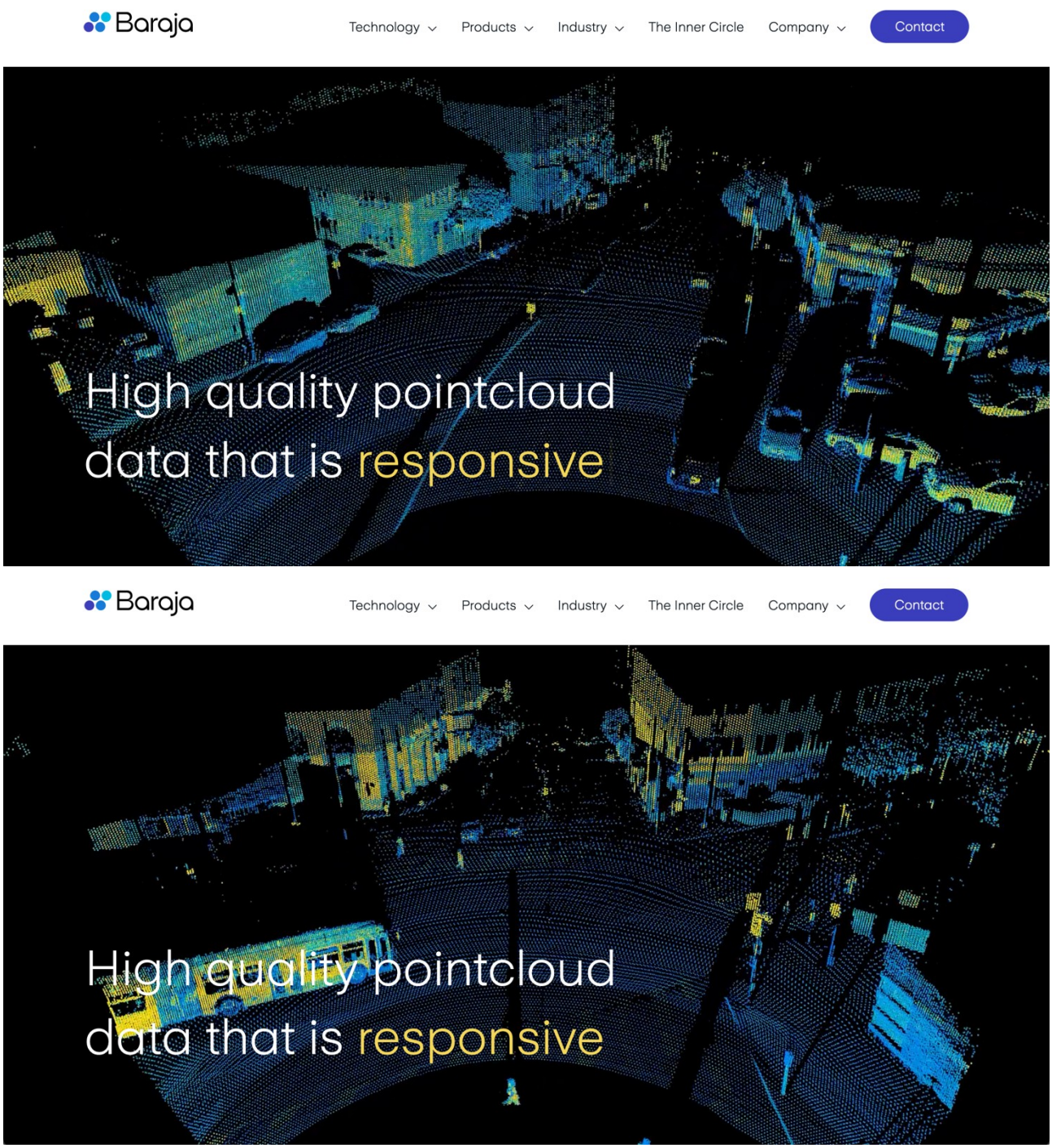
7. Aurora (USA), < https://aurora.tech/>

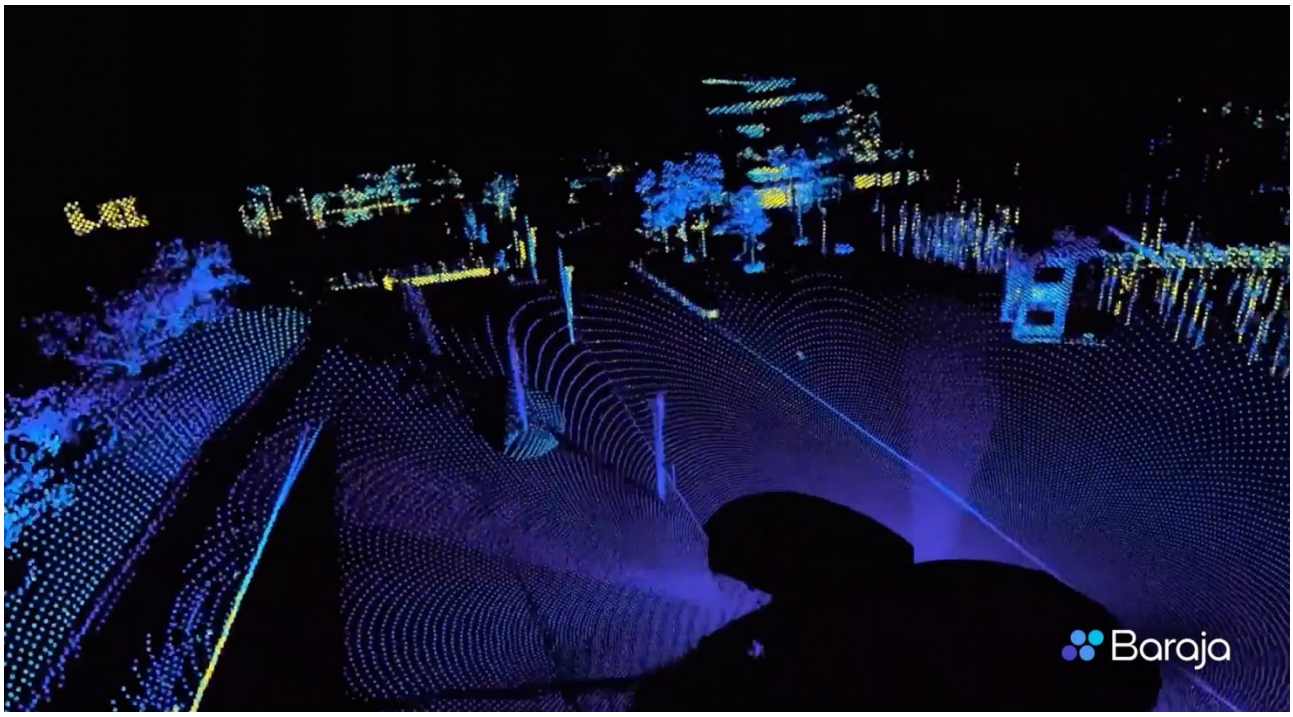
Source: < https://aurora.tech/aurora-driver>



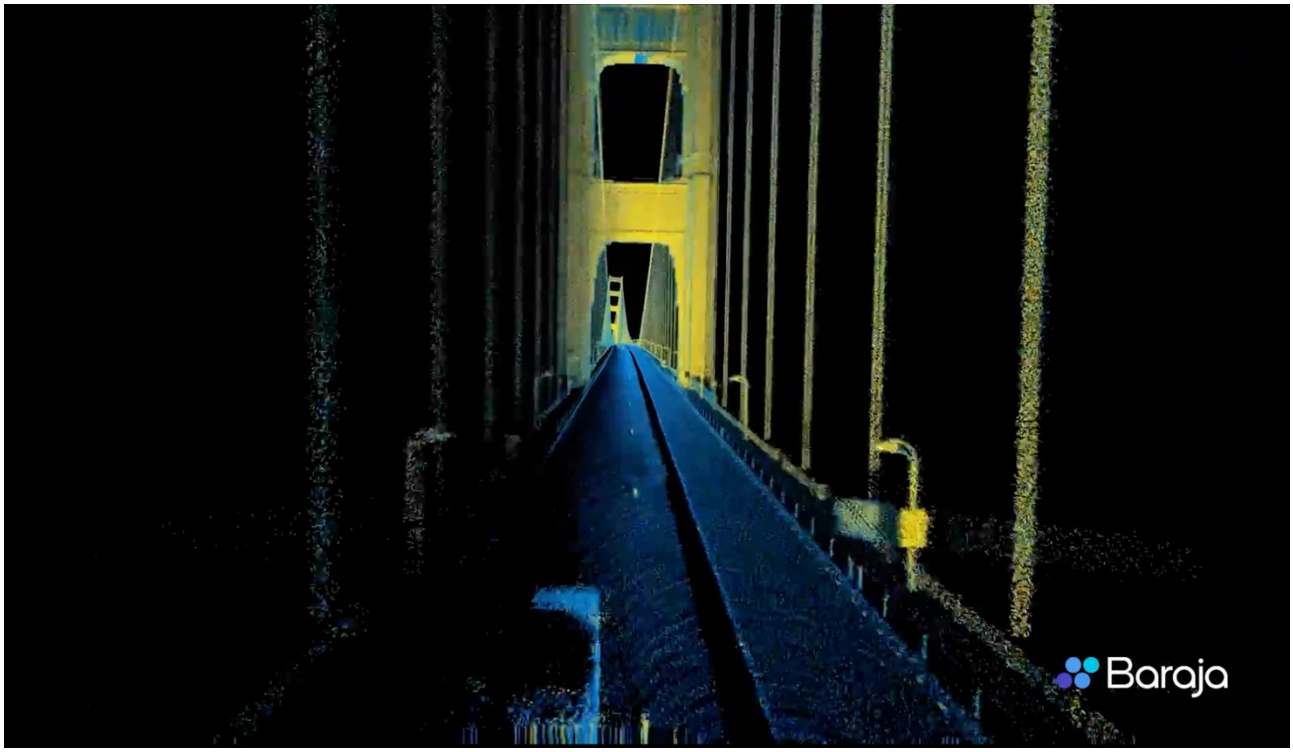
8. Baraja (Australia) < https://www.baraja.com/en>

Source: < https://www.baraja.com/en>


Baraja
Technology
Products
Industry
The Inner Circle
Company
Contact
High quality pointcloud
data that is responsive
Baraja
Technology
Products
Industry
The Inner Circle
Company
Contact
High quality pointcloud
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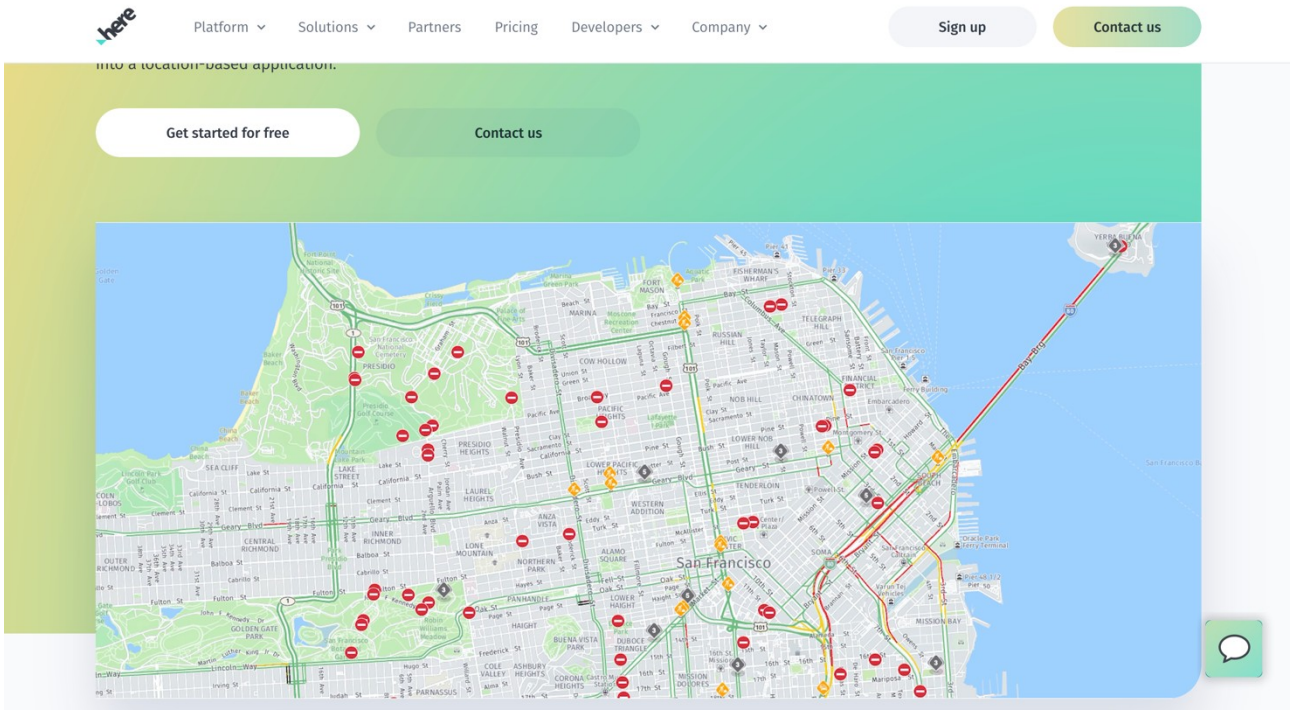


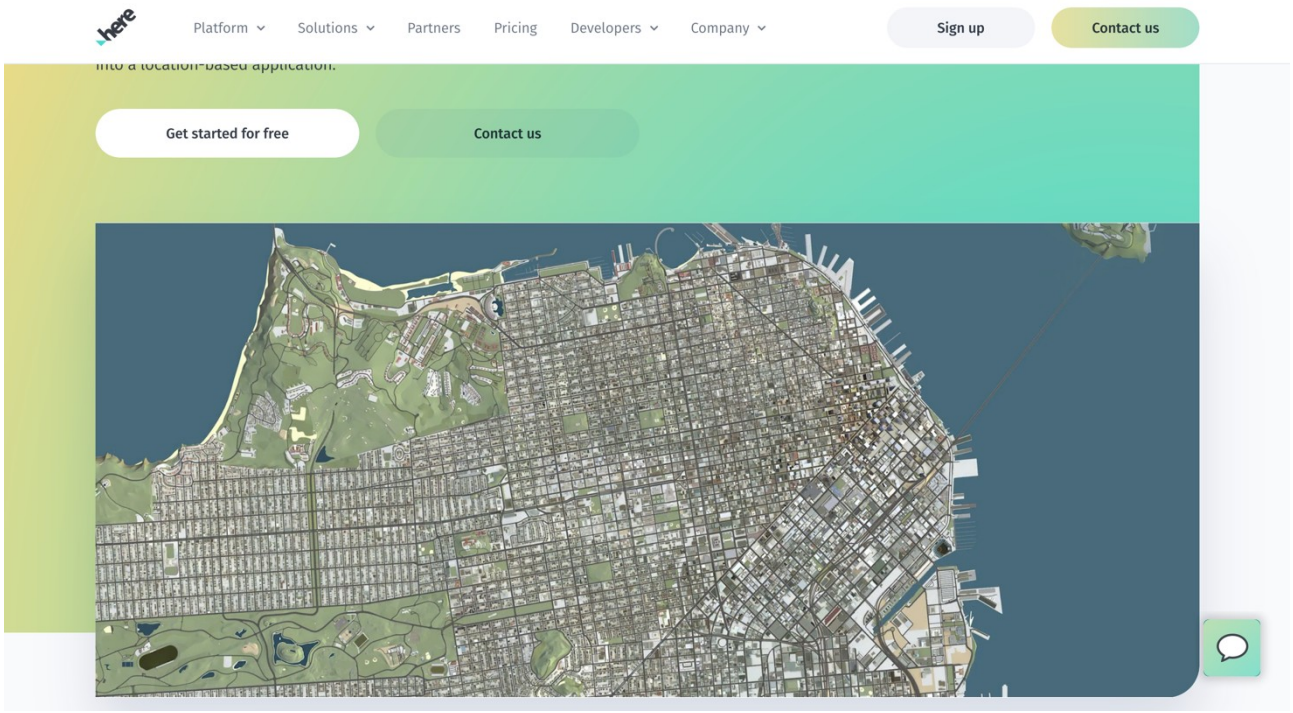
Source: < https://www.baraja.com/en/blog/precision-pointclouds-through-engineered-beam-divergence>

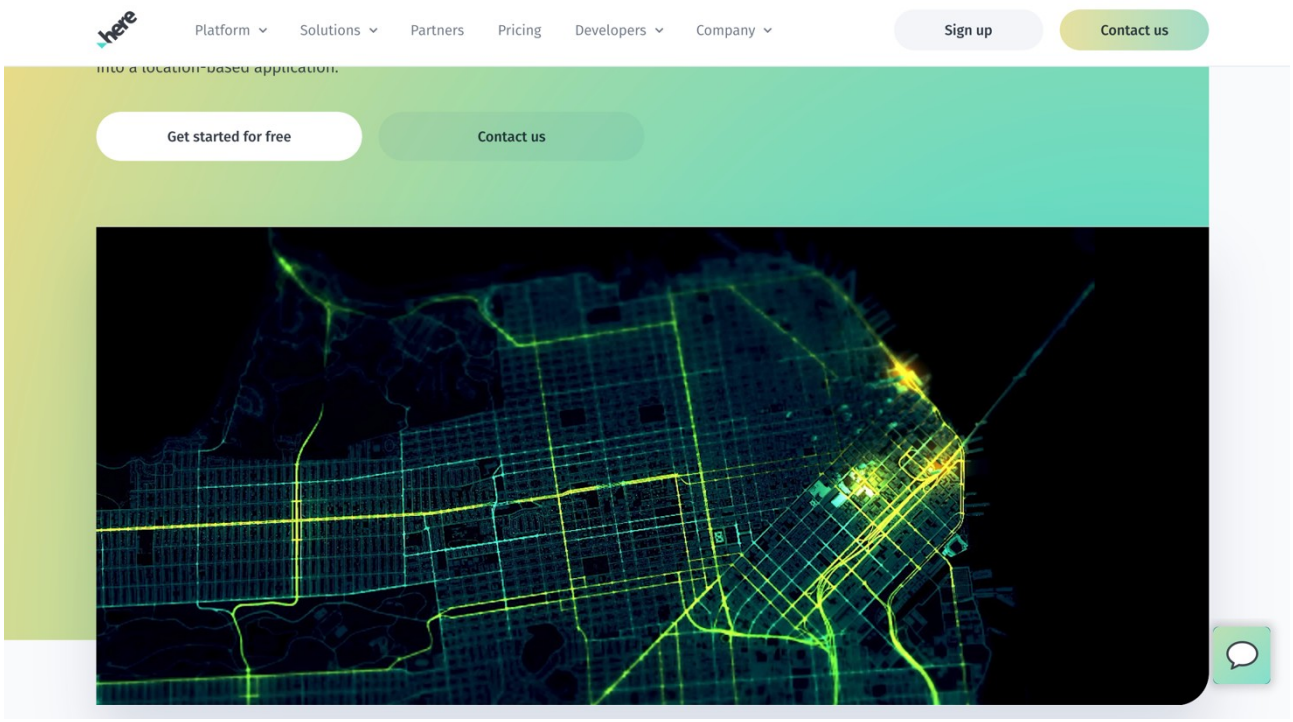


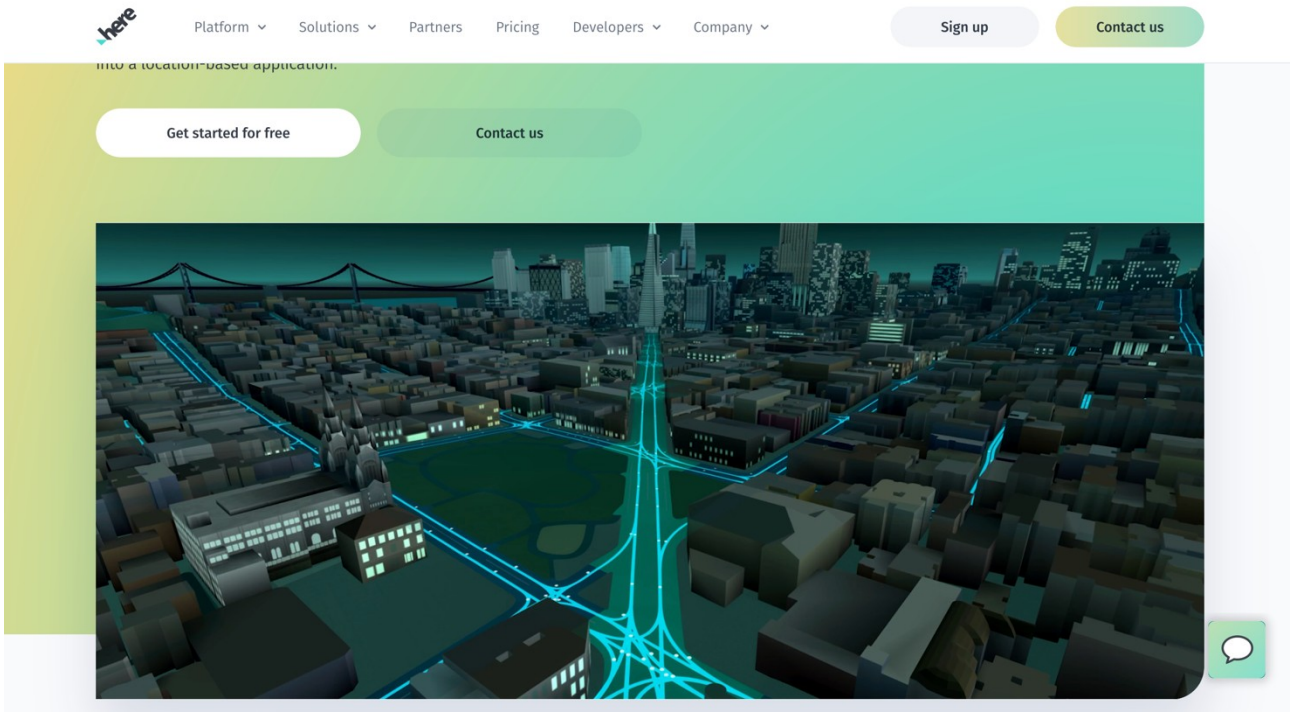
9. Bentley – Here technologies (Netherlands) < https://www.here.com/>

Source: < https://www.here.com/platform/map-data>


here
Platform
Solutions
Partners
Pricing
Developers
Company
Sign up
Contact us
Get started for free
Contact us
San Francisco

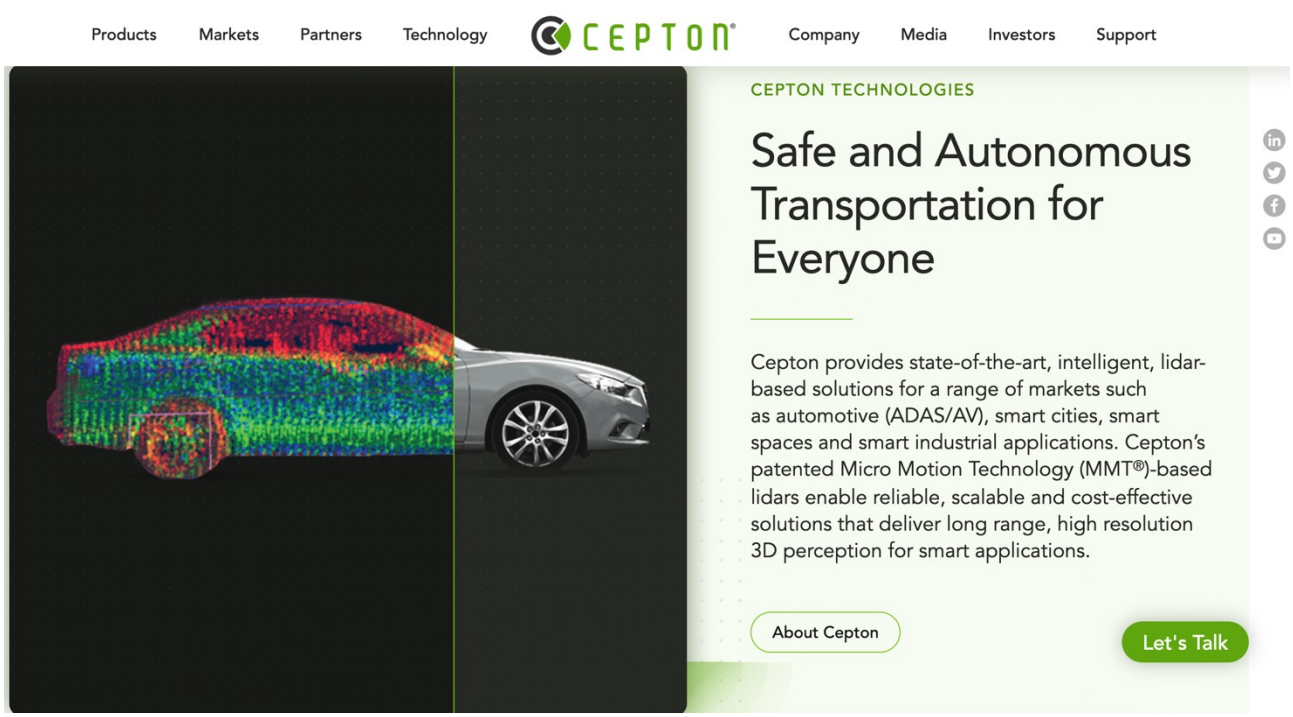

here
Platform
Solutions
Partners
Pricing
Developers
Company
Sign up
Contact us
Get started for free
Contact us





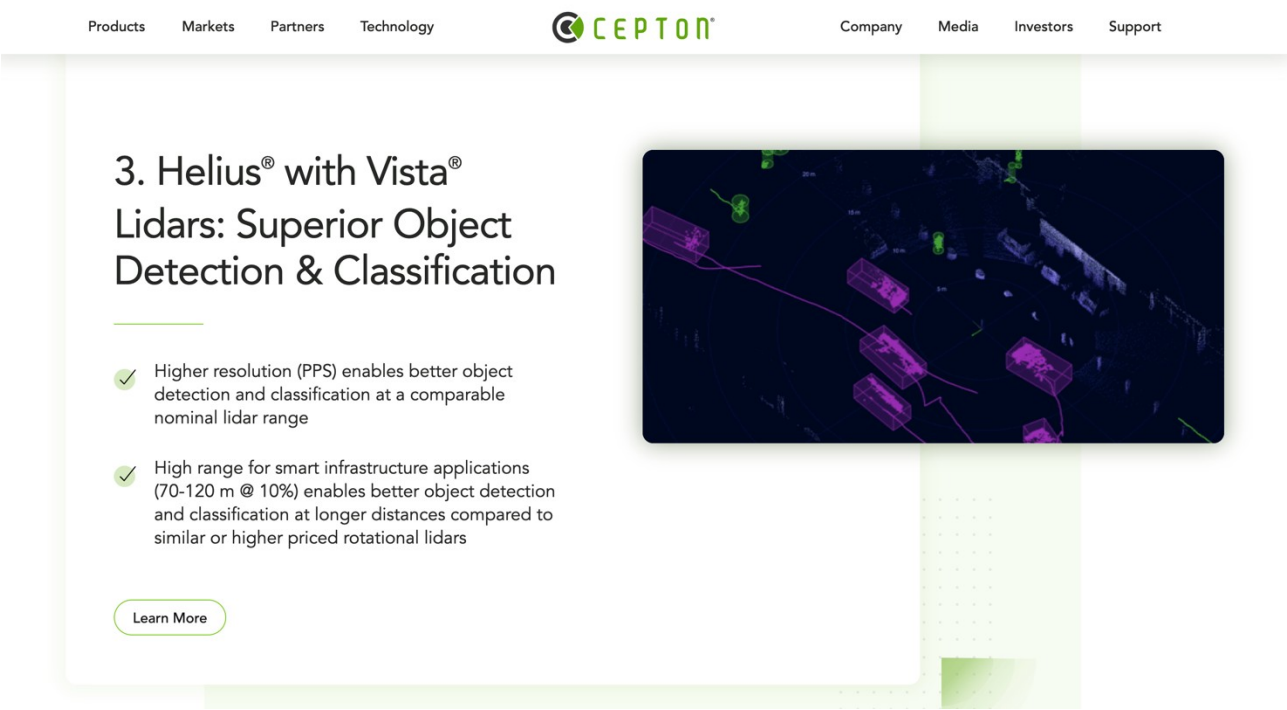
10. Blackmore
No website available.

11. Cepton (USA), < https://www.cepton.com/>
Source: < https://www.cepton.com/>

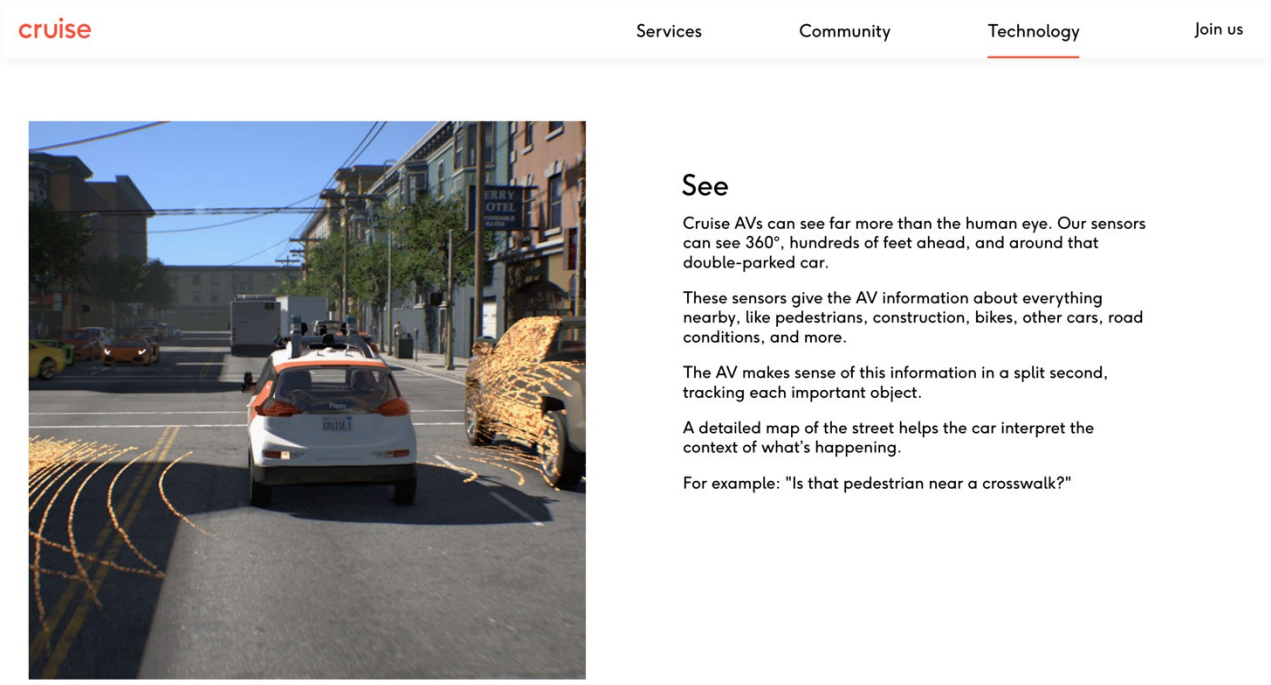


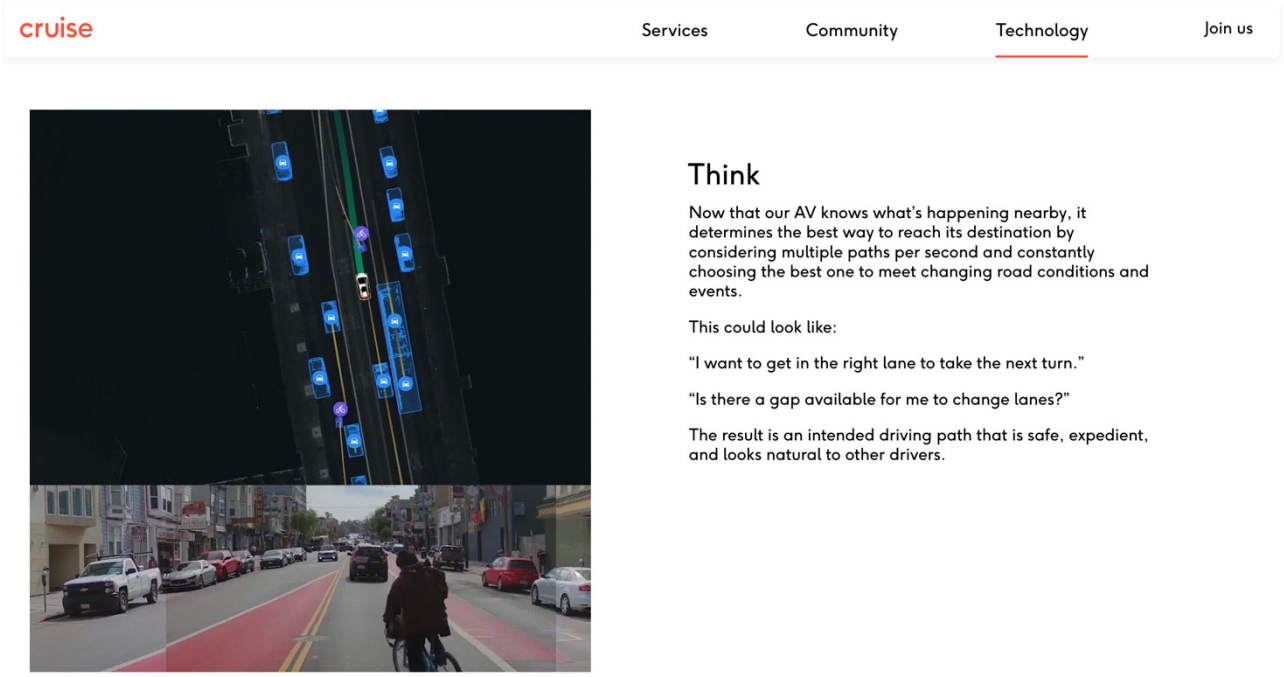
Source: < https://www.cepton.com/directional>





12. Cruise (USA), < https://www.getcruise.com/>
Source: < https://www.getcruise.com/technology>



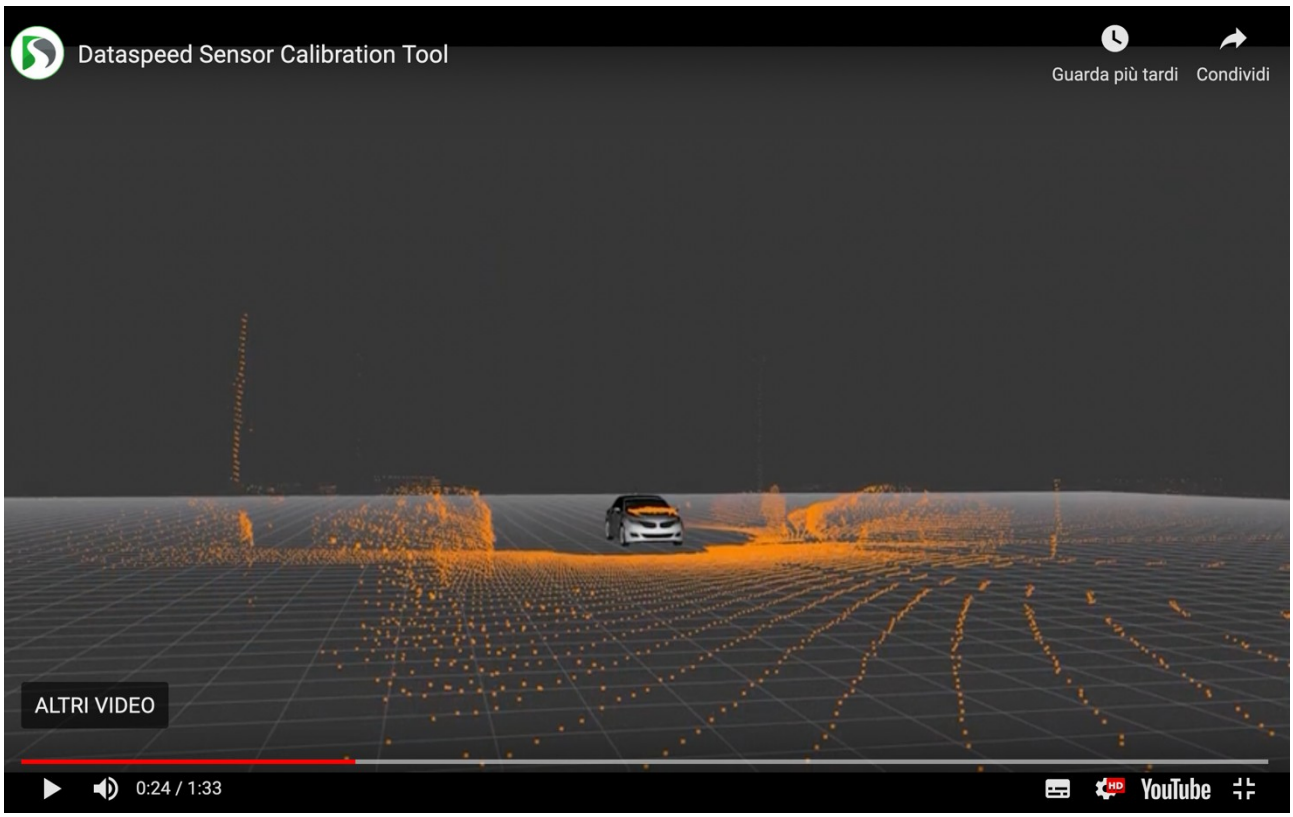


13. Daimler

No website available.

14. Dataspeed.Inc (USA), < https://www.dataspeedinc.com/>

Source: < https://www.dataspeedinc.com/autonomous-software/sensor-calibration-tool/

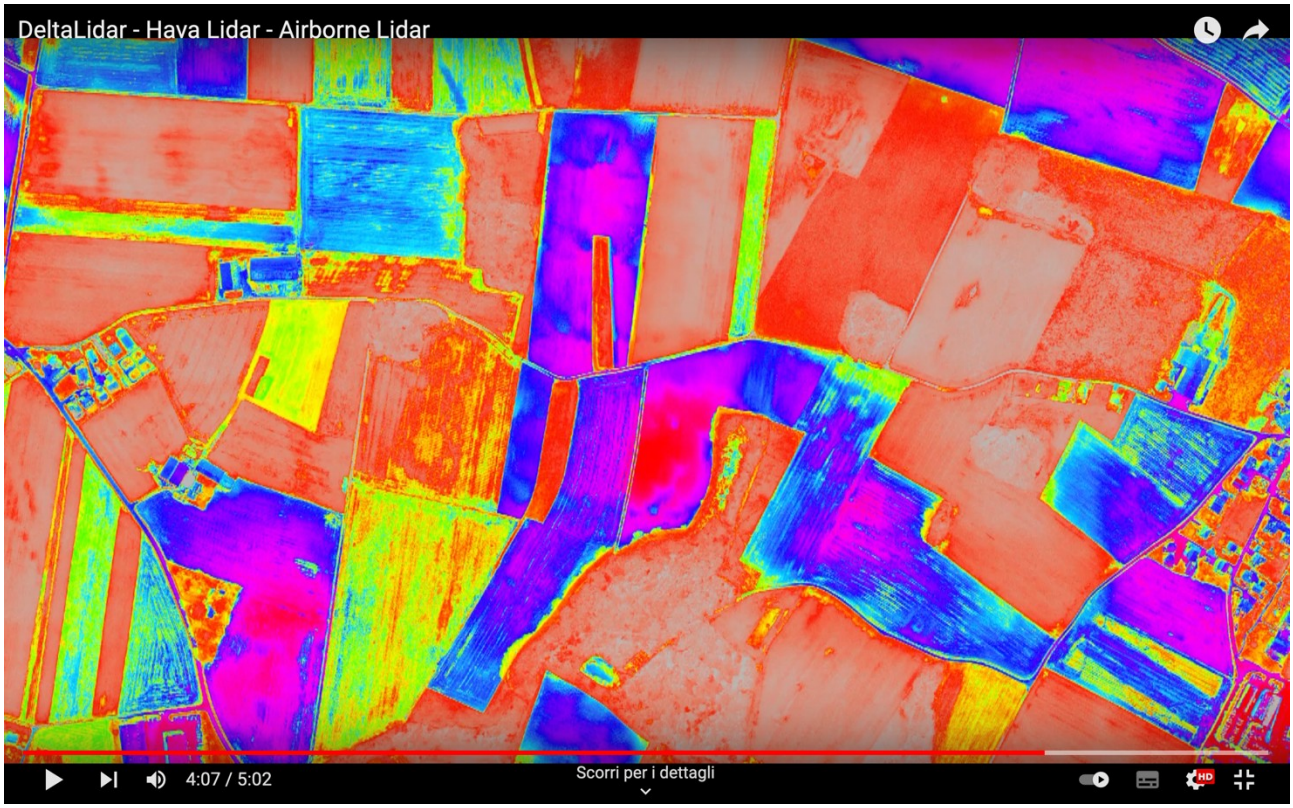


15. Deep Map

No website available.

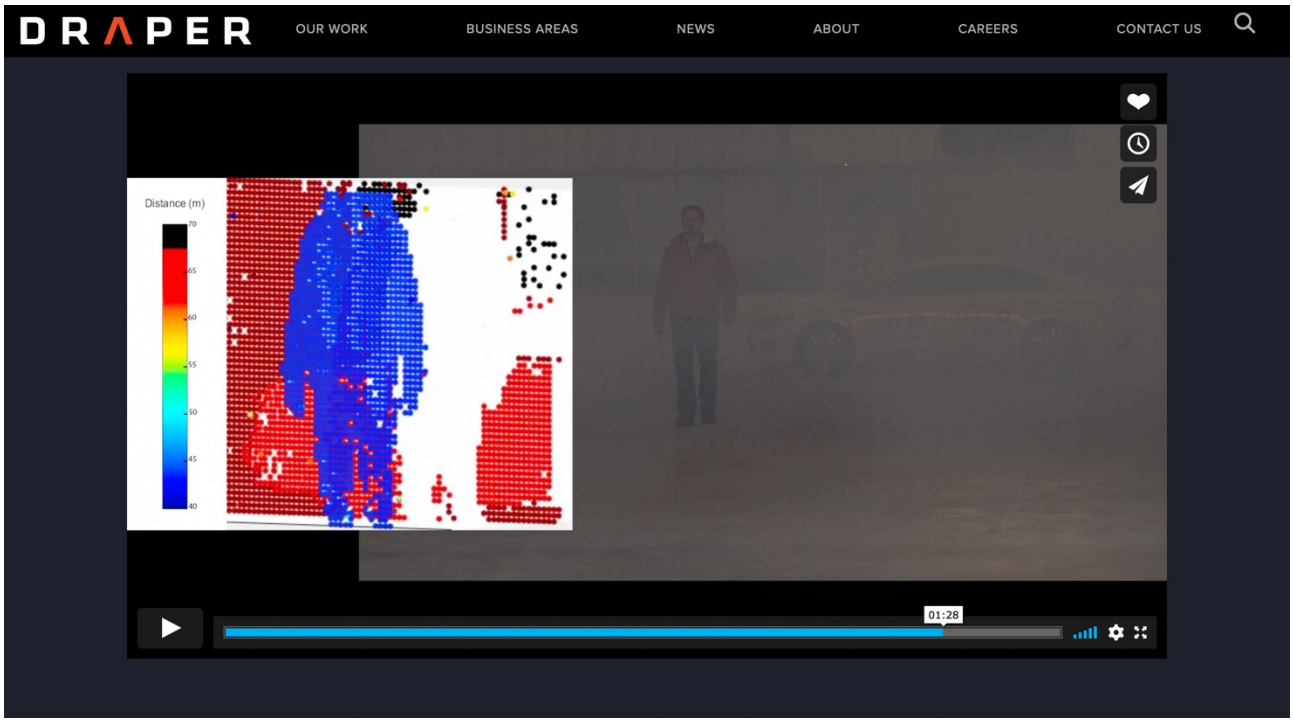
16. DeltaLidar (Turkey), < https://www.deltalidar.com/>

Source: < https://www.deltalidar.com/>



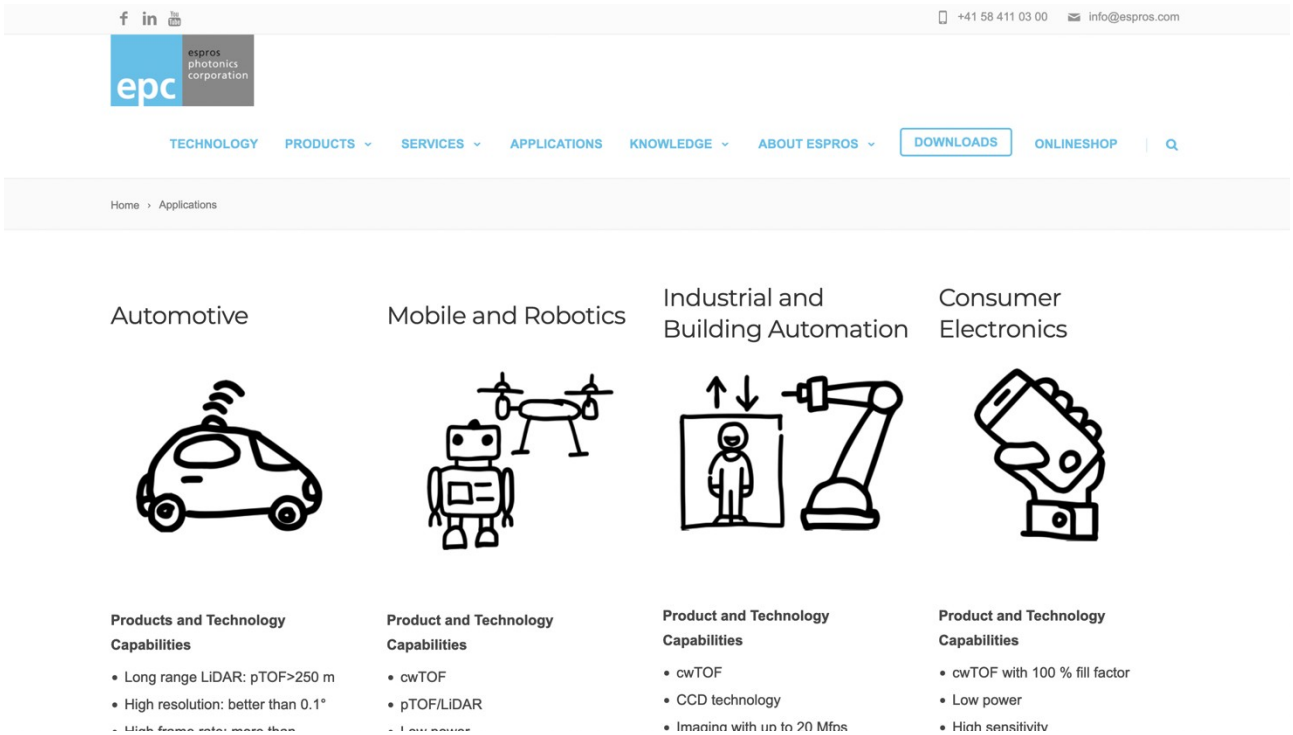
17. Draper (USA), < https://www.draper.com/>

Source: < https://www.draper.com/stories/hemera#hemera>



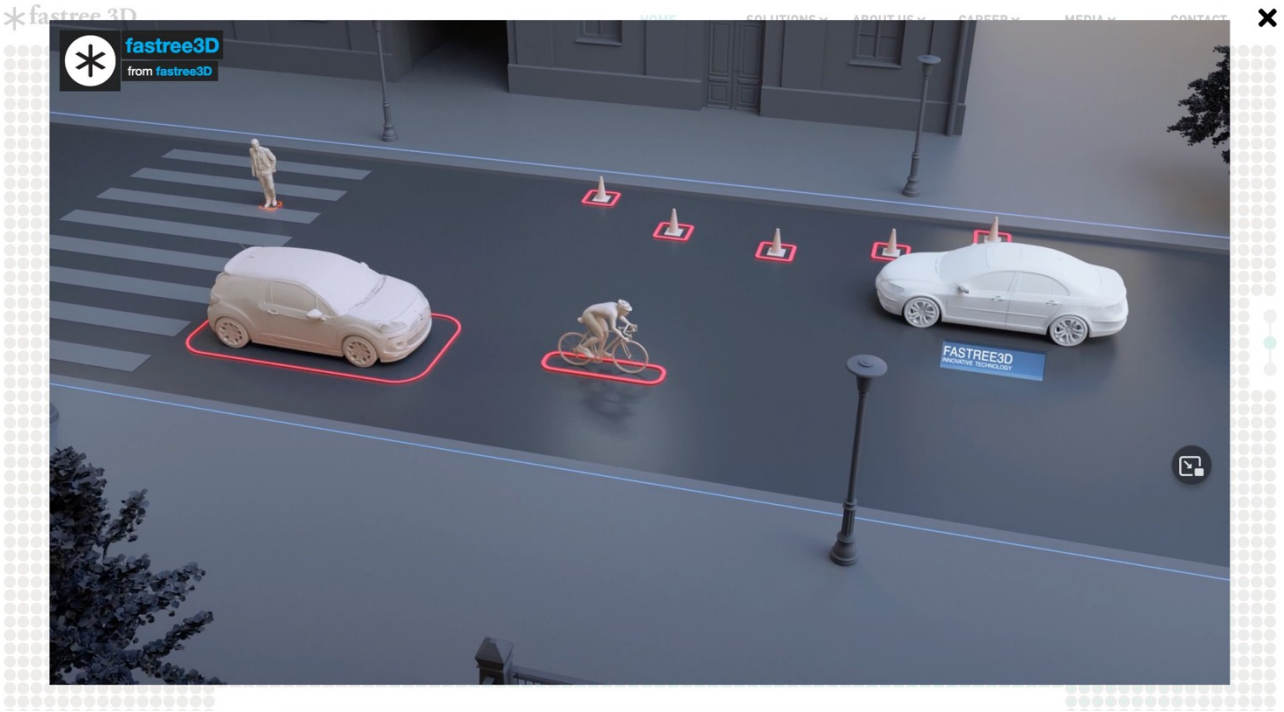
18. Espros (Switzerland), < https://www.espros.com/>

Source: < https://www.espros.com/tof-applications/>



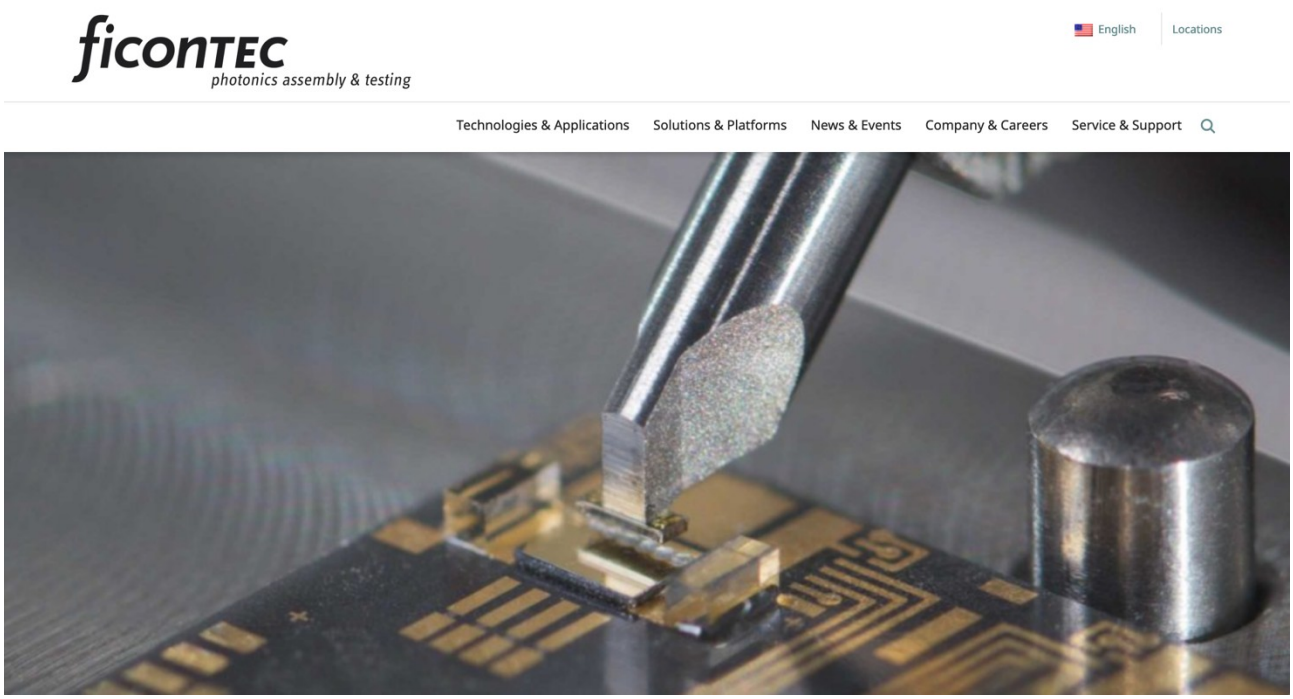
19. Fasttree 3d (Switzerland), < https://fastree3d.com/>

Source: < https://fastree3d.com/>



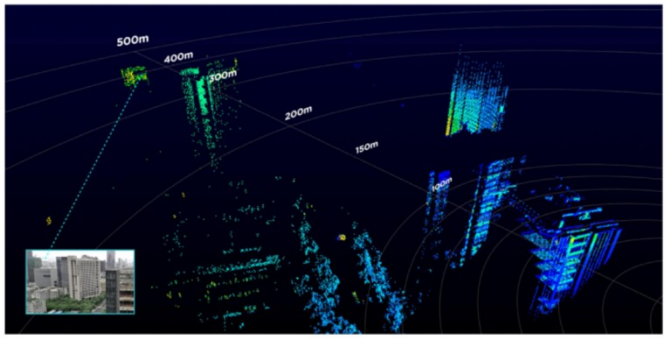
20. Ficontec (Germany), < https://www.ficontec.com/>

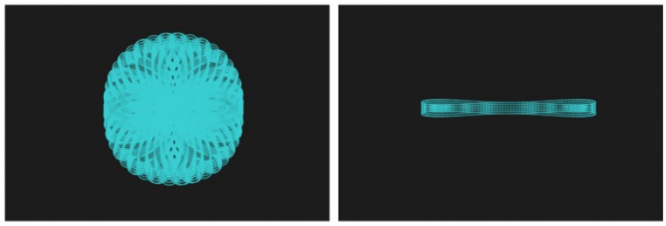
Source: < https://www.ficontec.com/technologies/>

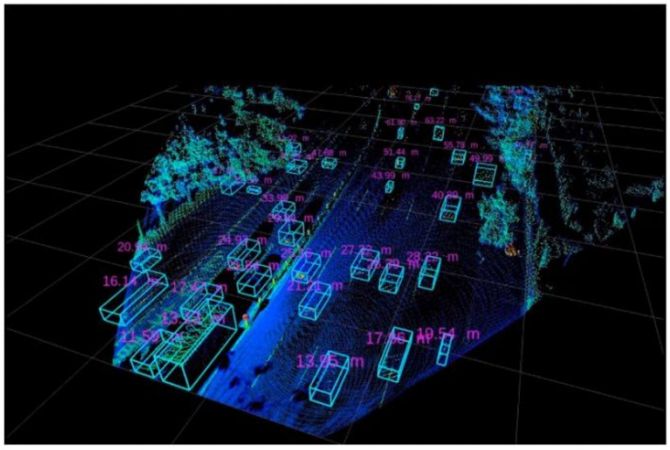


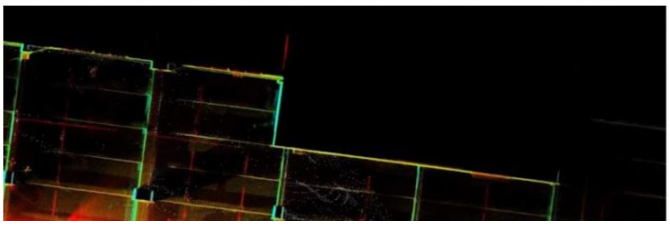
21. Geosun lidar (China), < https://www.geosunlidar.com/>

Source: < http://italian.geosunlidar.com/quality-13560166-750g-geosun-gs-100m-livox-avia-laser-vehicle-mounted-uav-lidar-system>

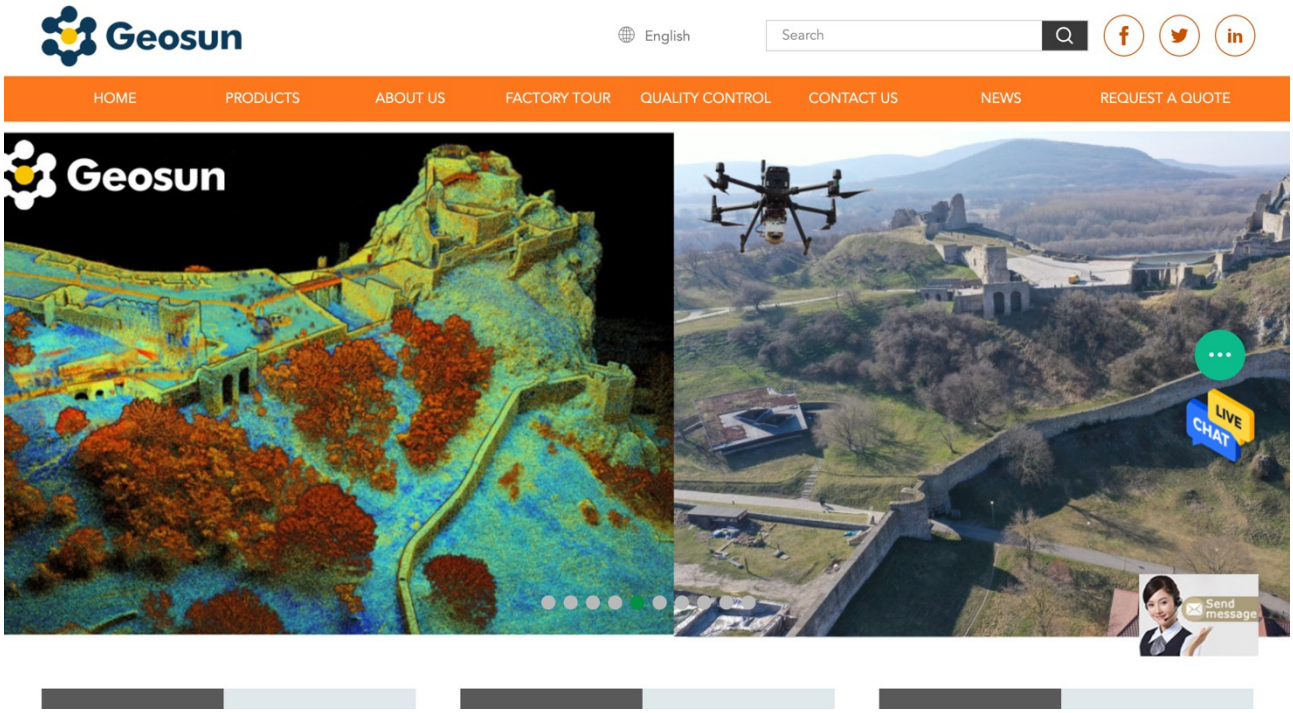






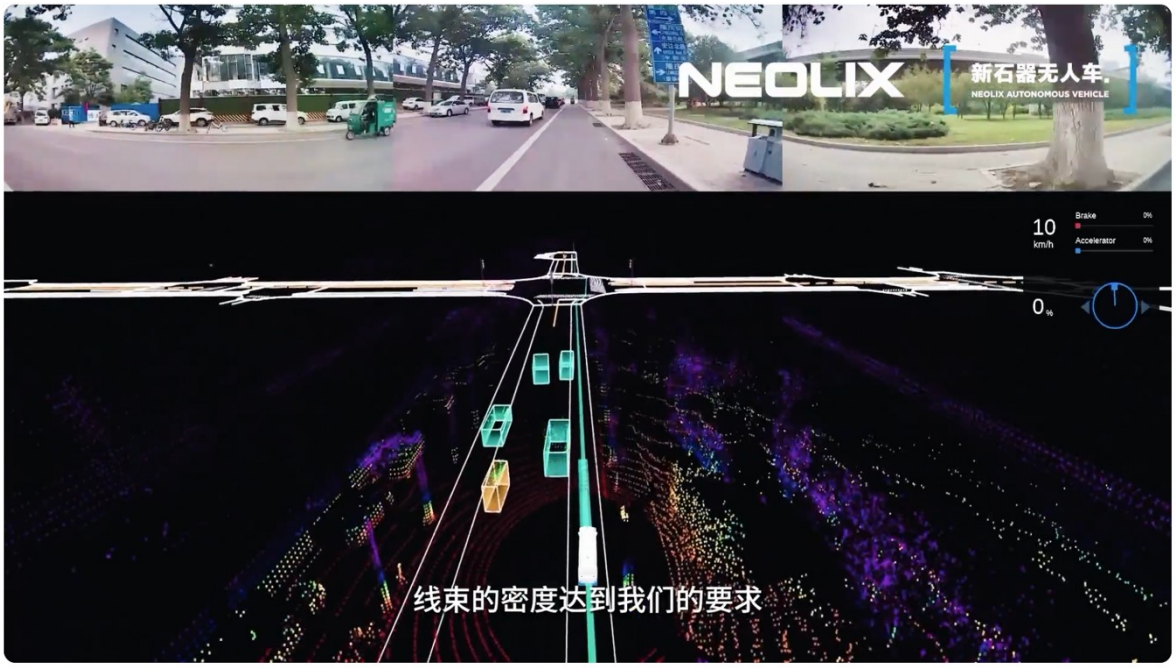


Source: < https://www.geosunlidar.com/>



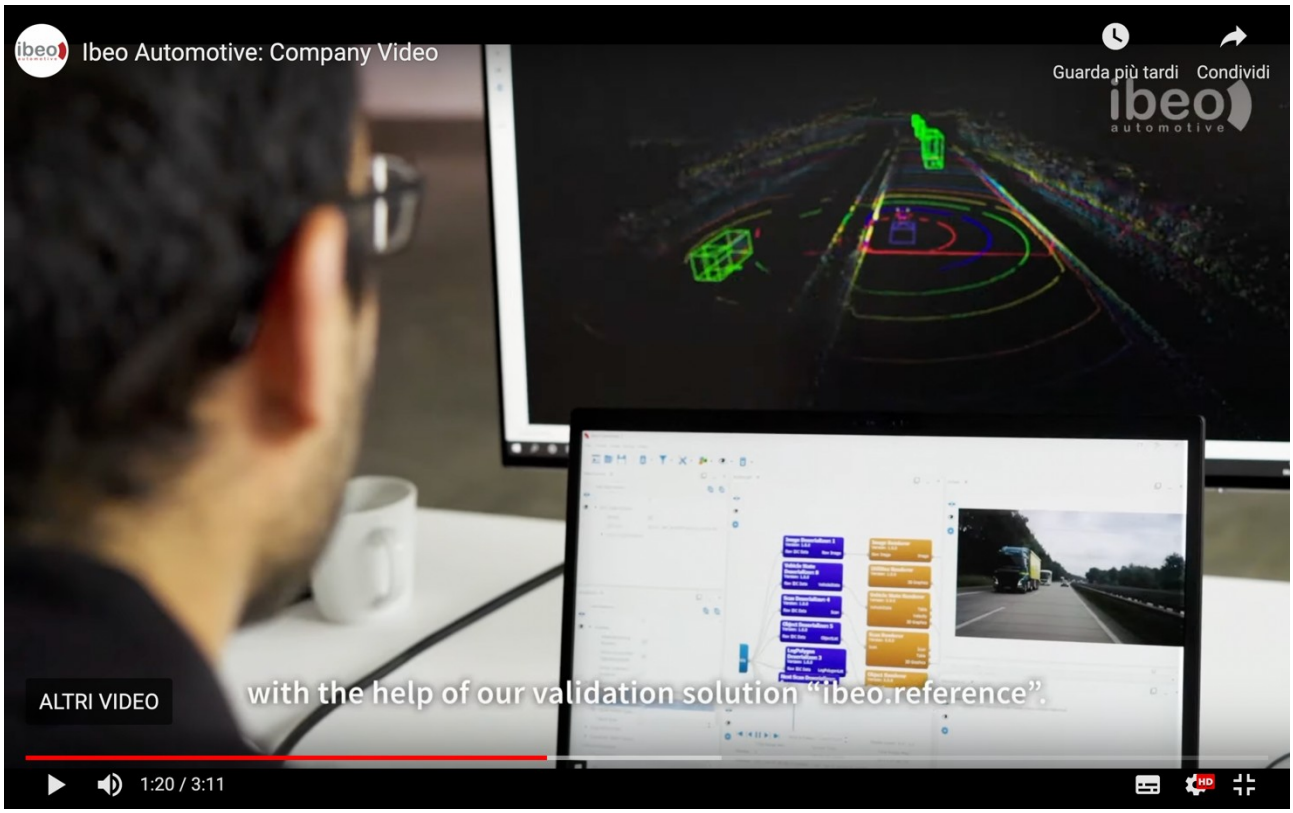
22. Hesai (China), < https://www.hesaitech.com/en>

Source: < https://www.hesaitech.com/en>

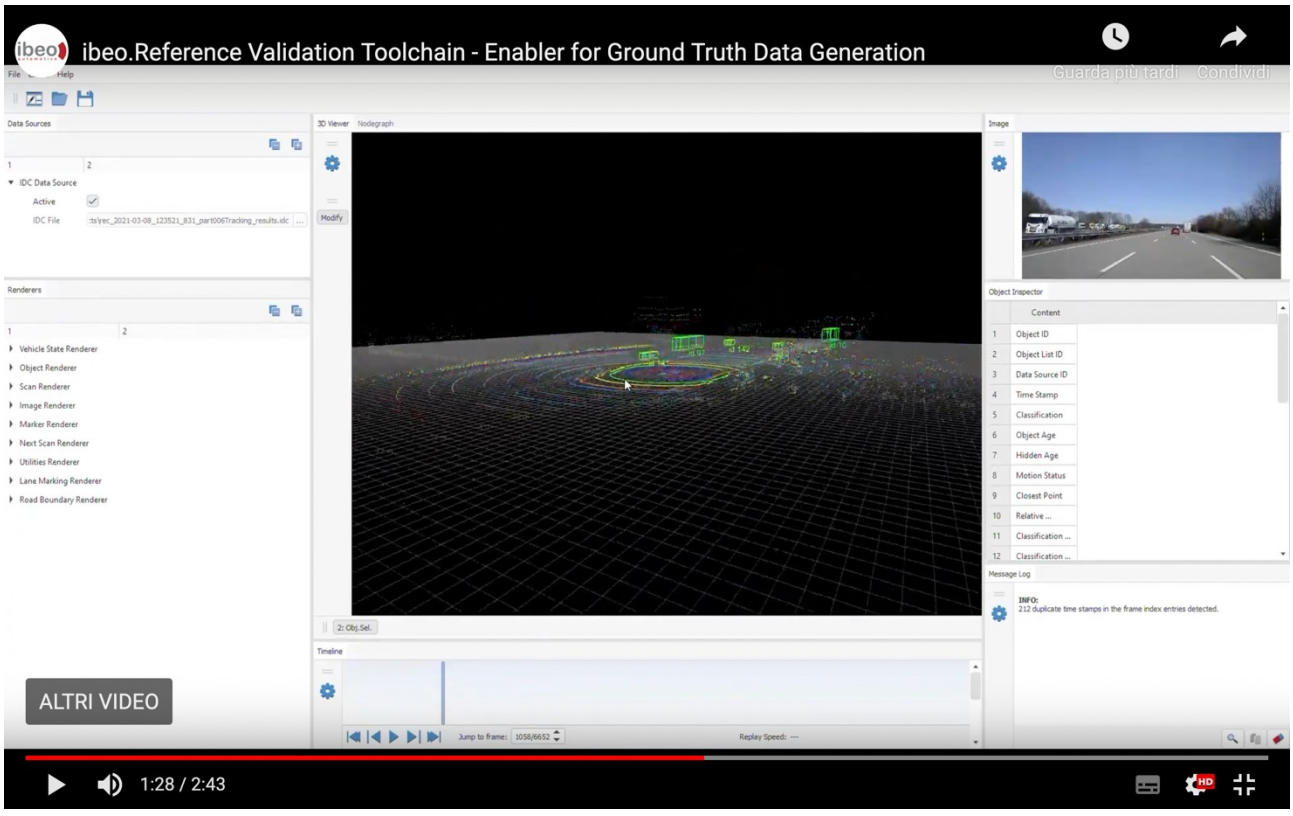


23. Ibeo (Germany), < https://www.ibeo-as.com/>

Source: < https://www.ibeo-as.com/>

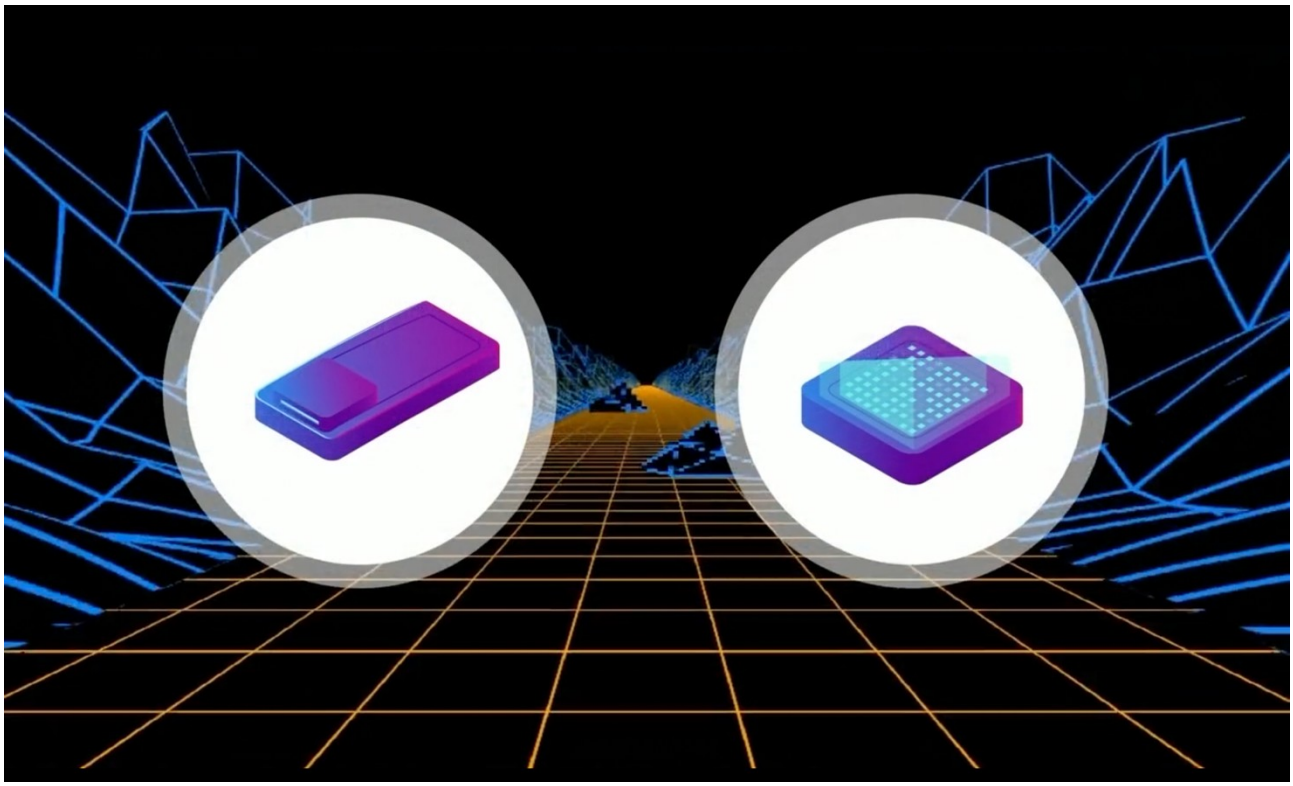


Source: https://www.ibeo-as.com/de/loesungen/loesungsdetailseiten/validierung



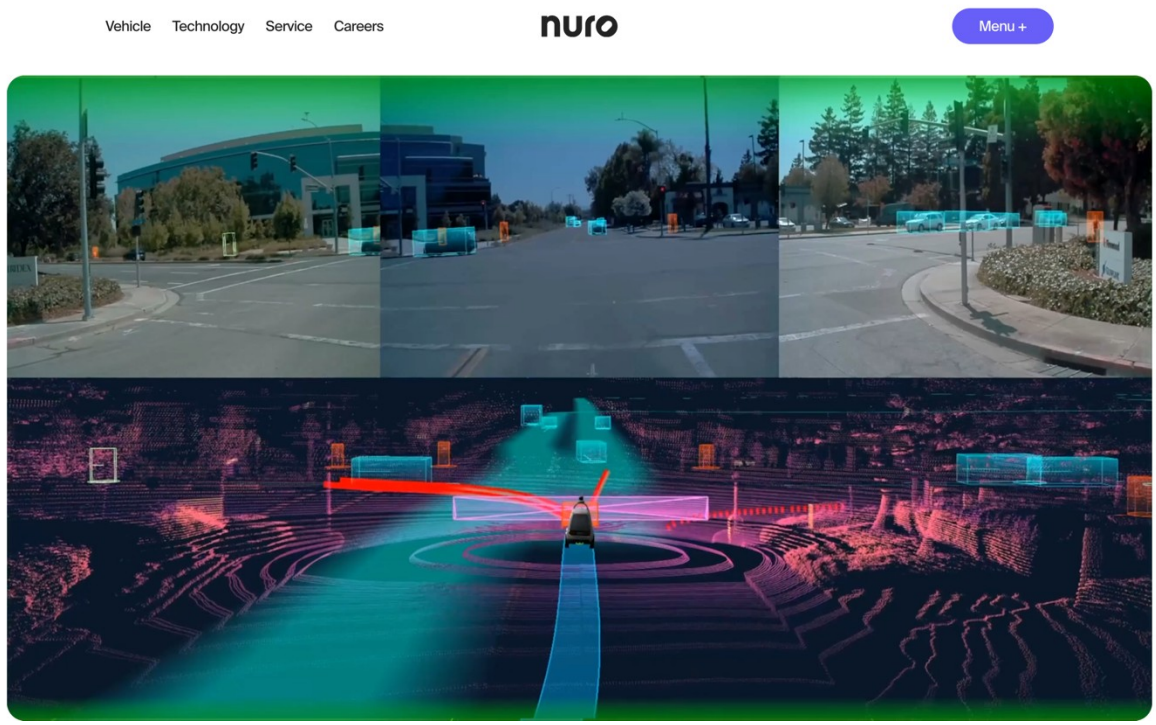
24. II-VI (USA), < https://ii-vi.com/>

Source: < https://ii-vi.com/automotive-market/>



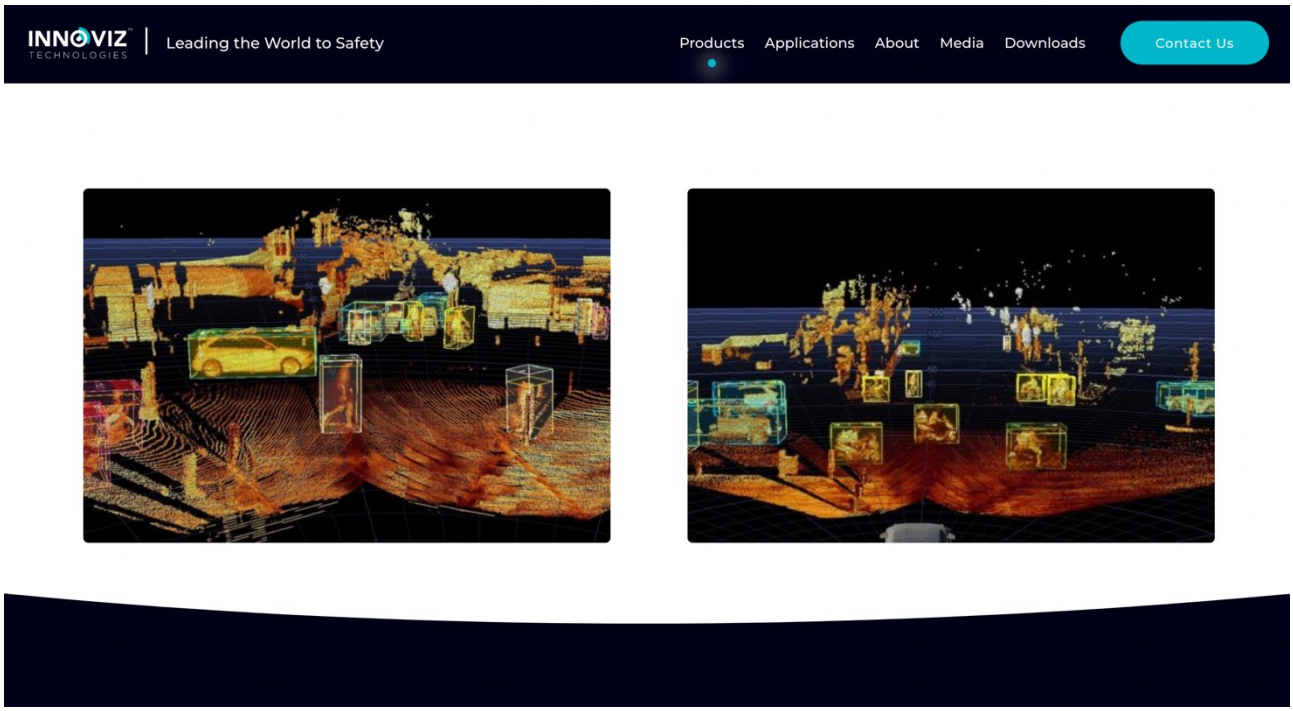
25. Nuro (USA), < https://www.nuro.ai/>

Source: < https://www.nuro.ai/technology>



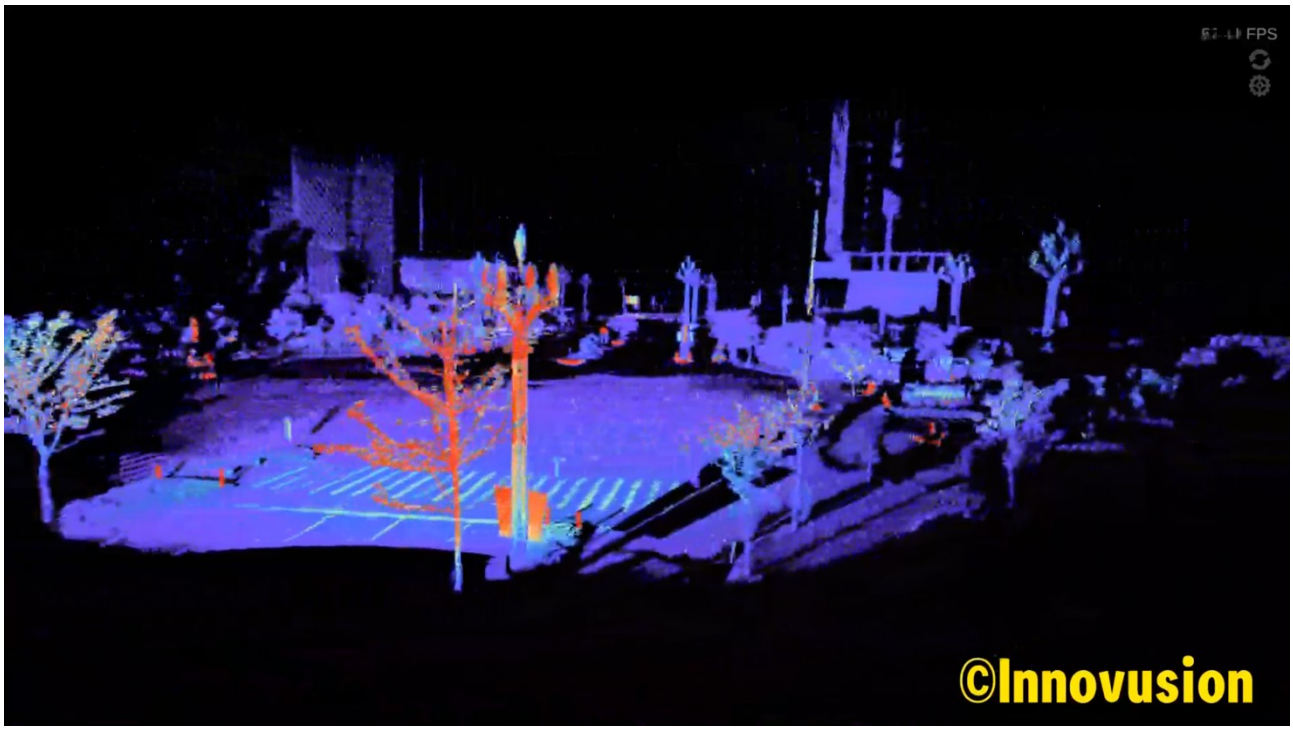
26. Innoviz (Israel), < https://innoviz.tech/>

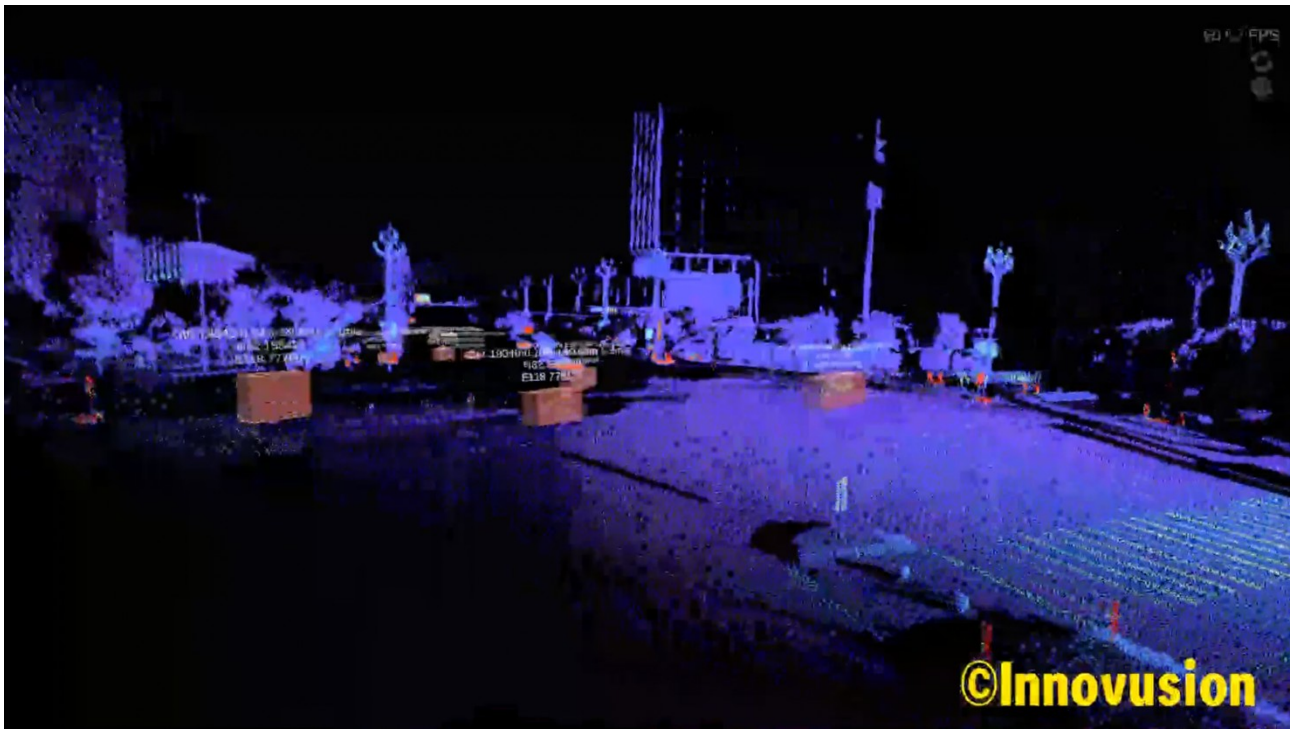
Source: < https://innoviz.tech/perception-software>



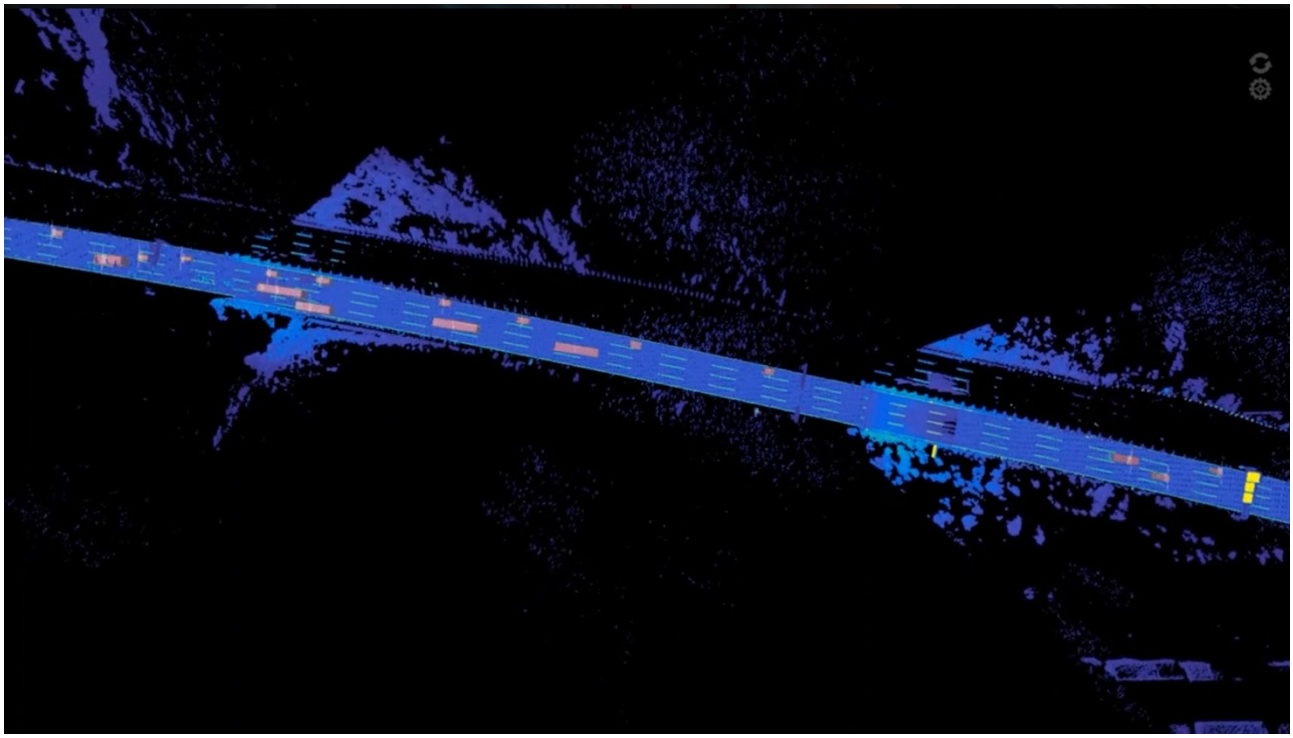
27. Innovusion (USA), <https://www.innovusion.com/>

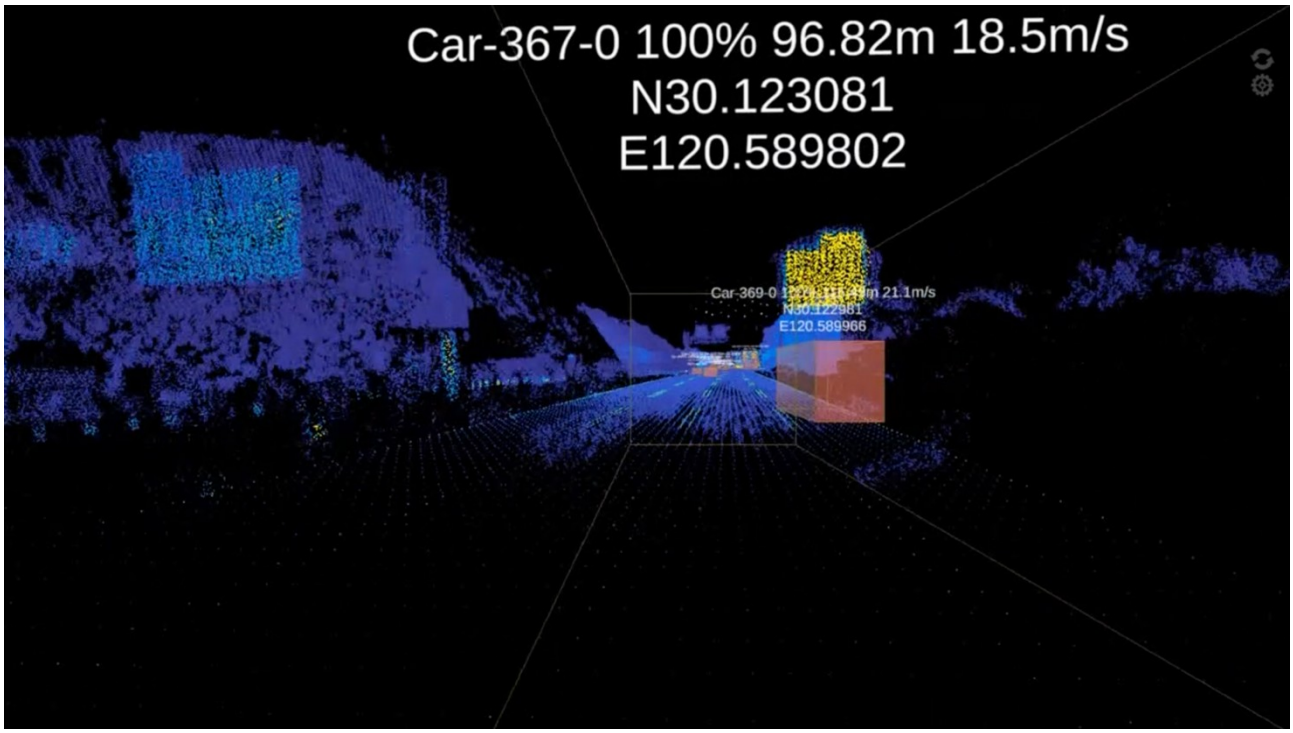
Source: < https://innovusion.com/applications-1>



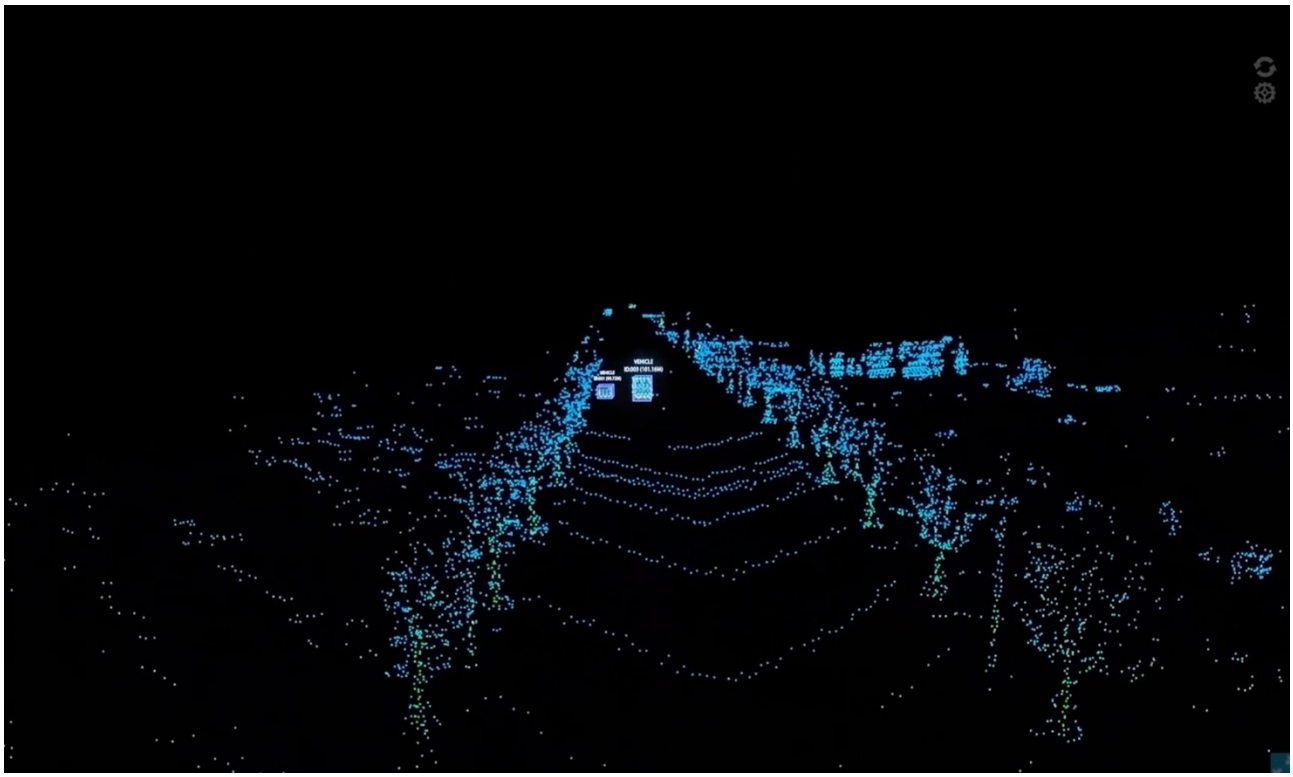


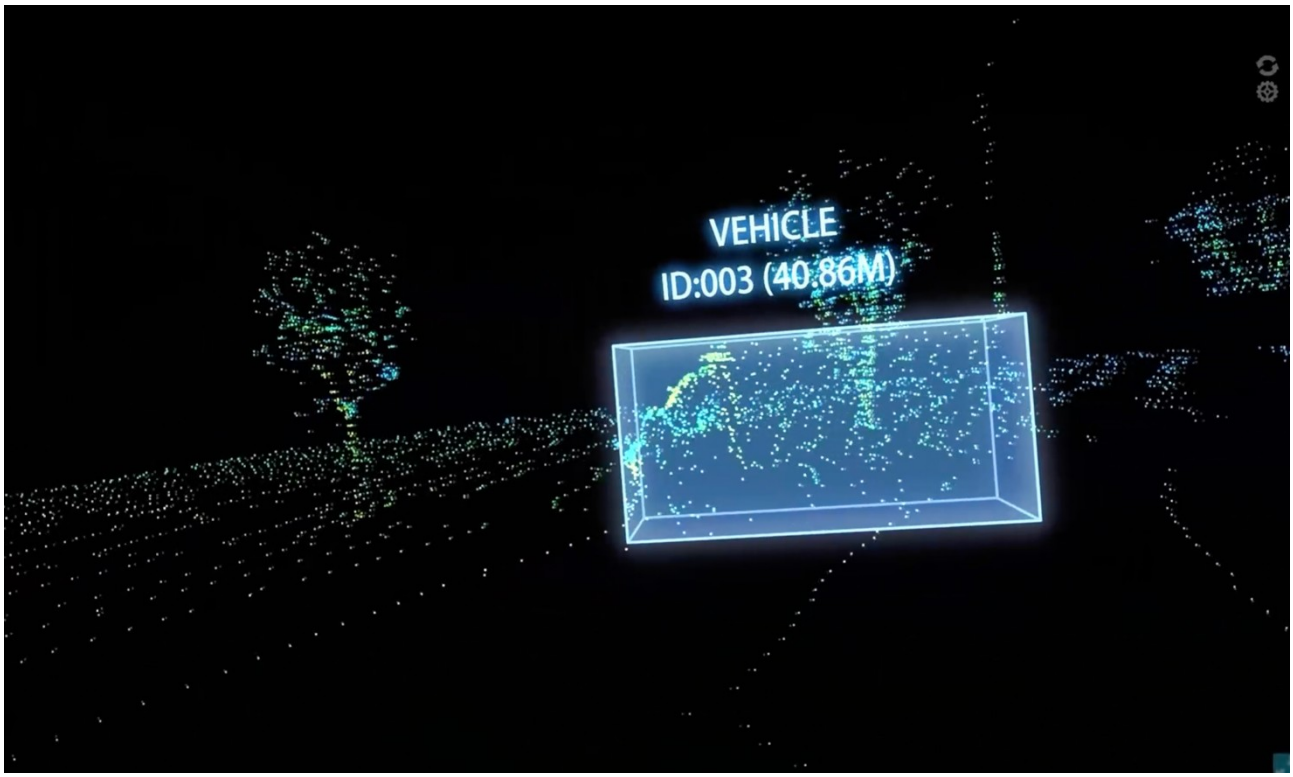
Source: < https://innovusion.com/applications-2>





Source: < https://innovusion.com/applications-4>





28. Kodiak (USA), <https://kodiak.ai/>

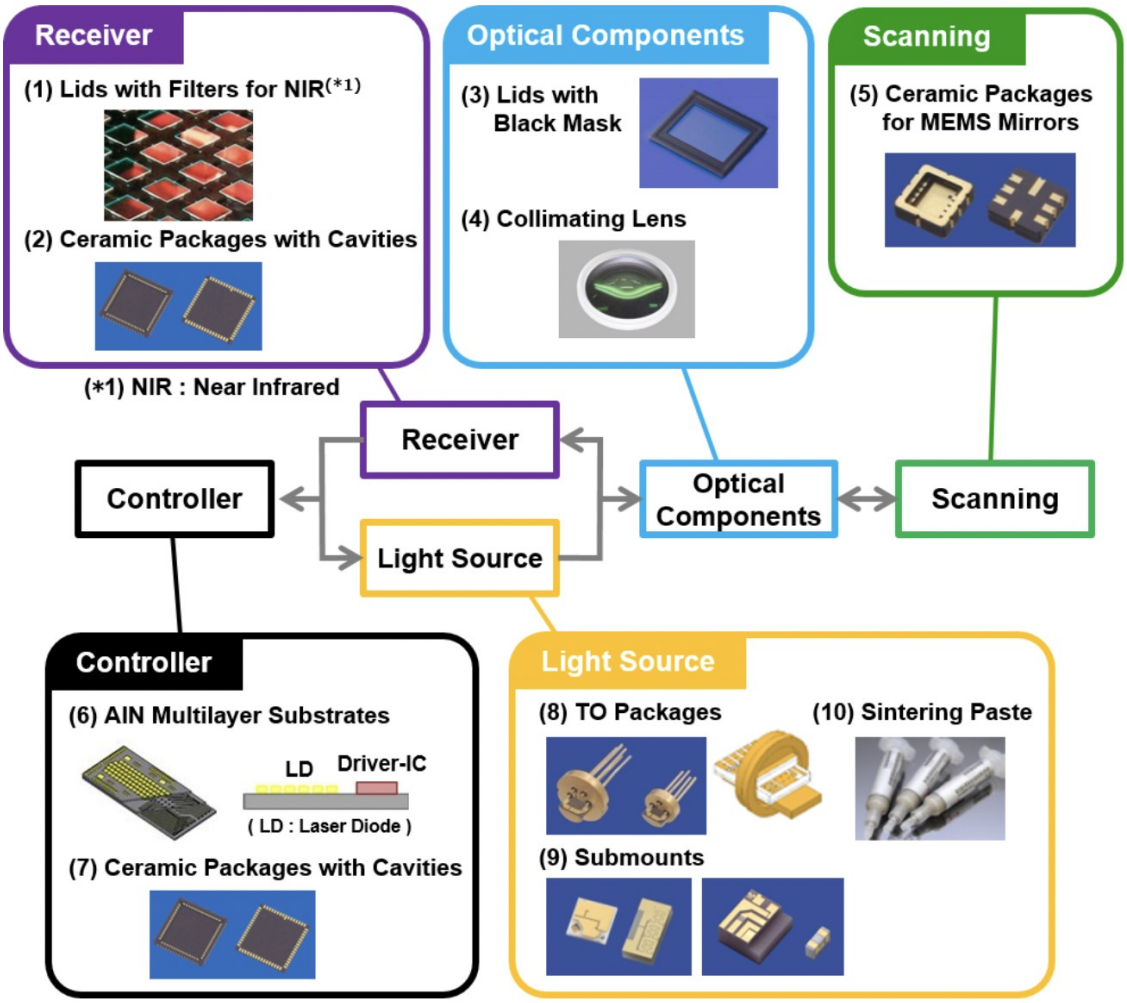
Source: < https://kodiak.ai/technology/>



29. Kyocera (USA), < https://global.kyocera.com/index.html>

Source: < https://global.kyocera.com/prdct/semicon/semi/lidar/>

Kyocera provides a wide range of custom and standard packages and lids to support each critical component of an automotive LiDAR module, including multi-layer ceramic packages with high strength and high thermal conductivity to support package miniaturization and increase thermal dissipation, high thermal conductivity die attach epoxies and sintering pastes, glass lids for sealing and lenses for collimating light. Kyocera's products can provide the LiDAR design a unique combination of tools to meet various LiDAR packaging requirements.

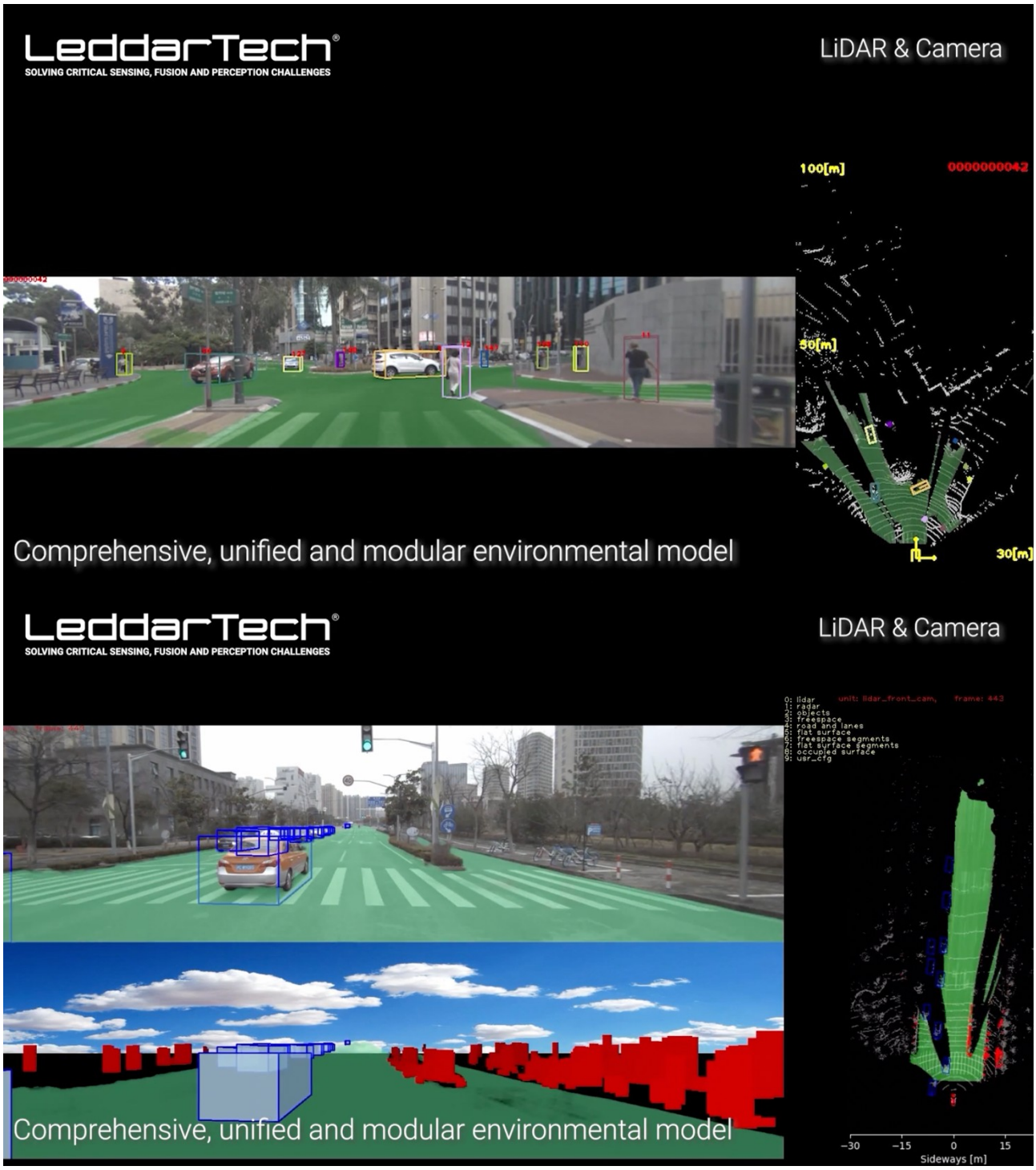


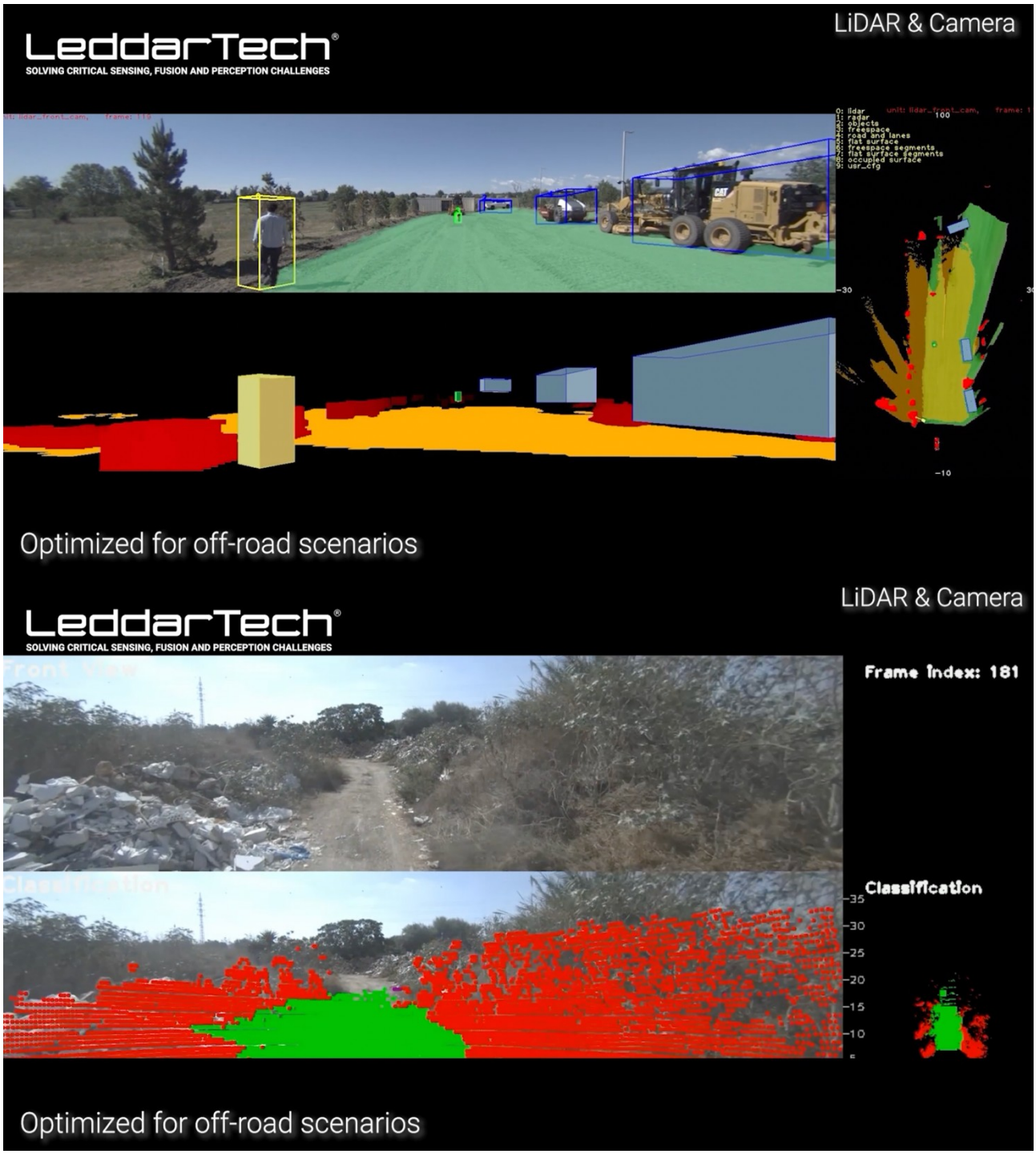
Source: < https://global.kyocera.com/index.html>

30. Labsphere (USA), https://www.labsphere.com/

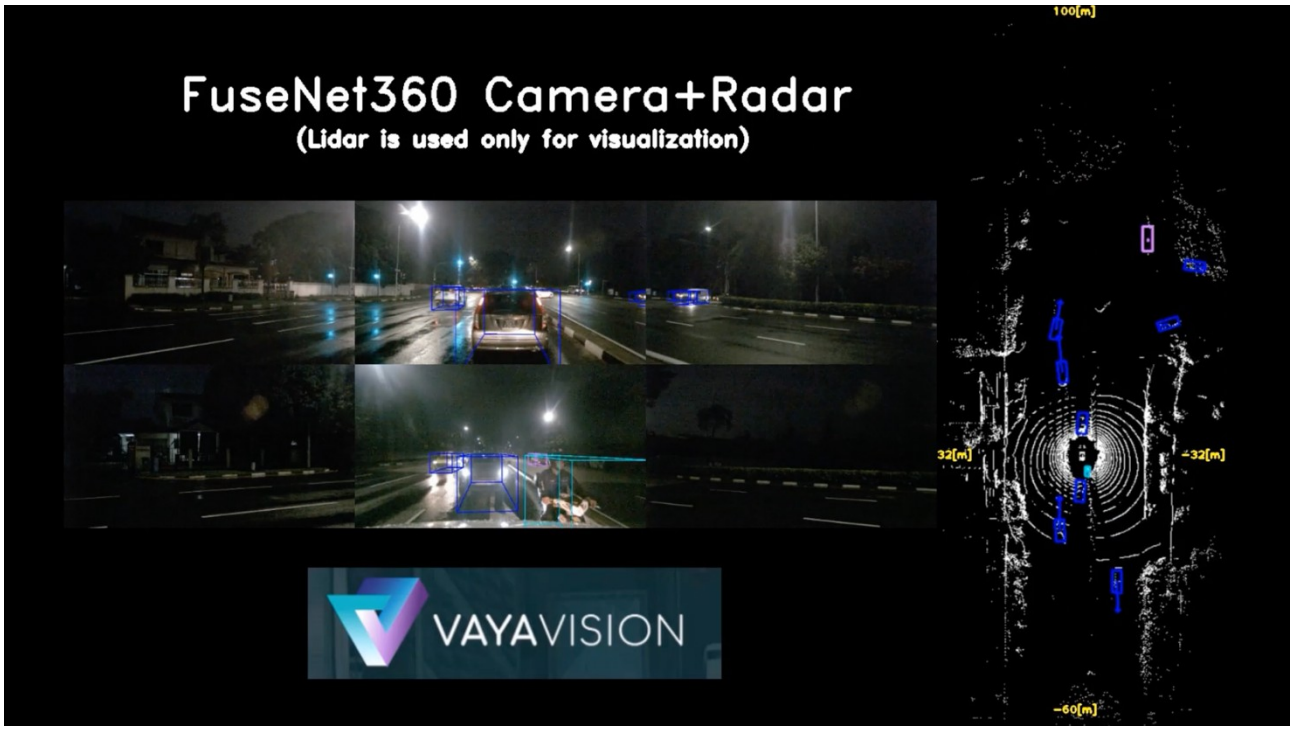
No website available.

31. Leddartech (Canada), <https://leddartech.com/>


LeddarTech®
SOLVING CRITICAL SENSING, FUSION AND PERCEPTION CHALLENGES
LiDAR & Camera
100[m]
30[m]
30[m]
Comprehensive, unified and modular environmental model
LeddarTech®
SOLVING CRITICAL SENSING, FUSION AND PERCEPTION CHALLENGES
LiDAR & Camera
0: lidar
1: radar
2: objects
3: freespace
4: road and lanes
5: flat surface
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Comprehensive, unified and modular environmental model

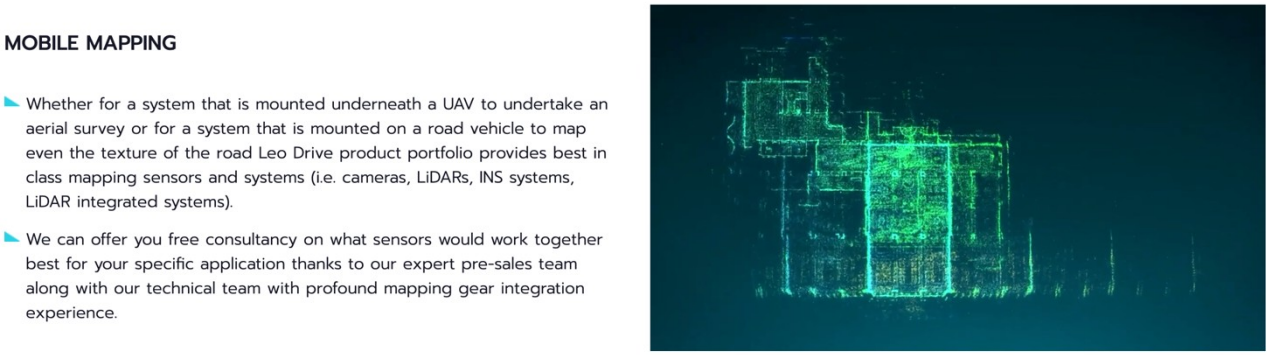


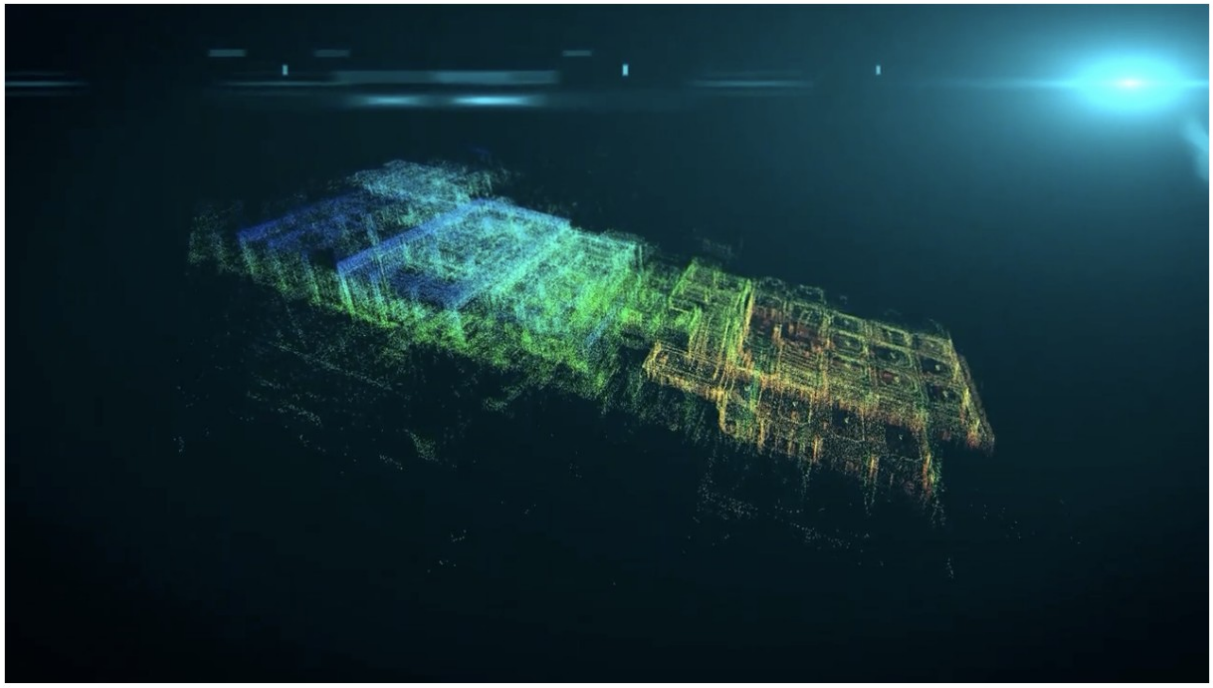
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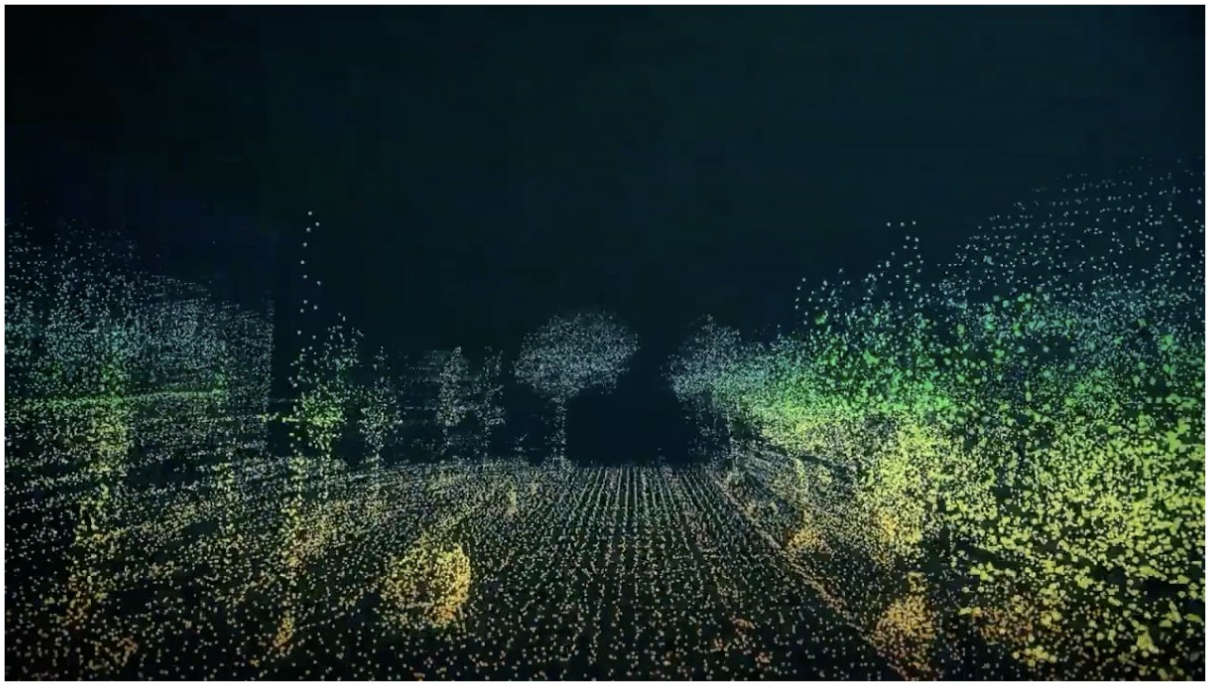


32. Leo Drive Ai (Turkey), <https://leodrive.ai/leodrive>

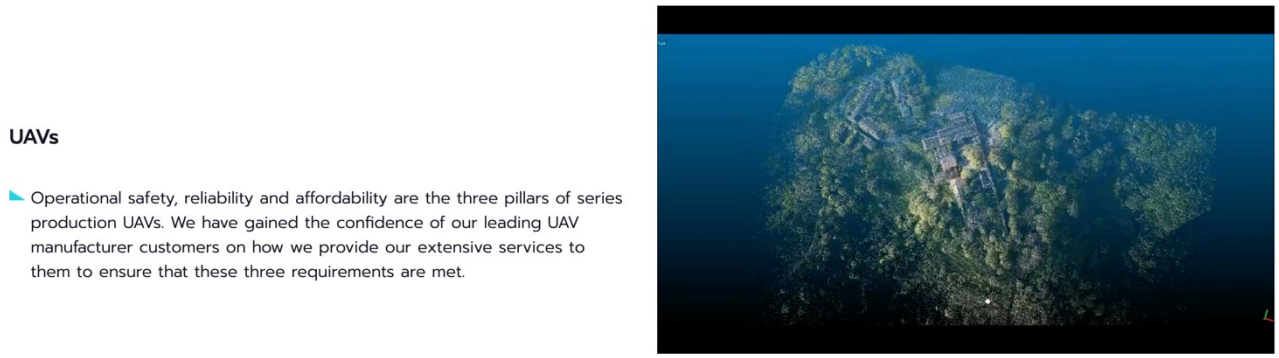
Source: < https://leodrive.ai/mobile-mapping>







Source: < https://leodrive.ai/uavs>



33. Leonardo Electronics (USA), https://www.leonardo.us/

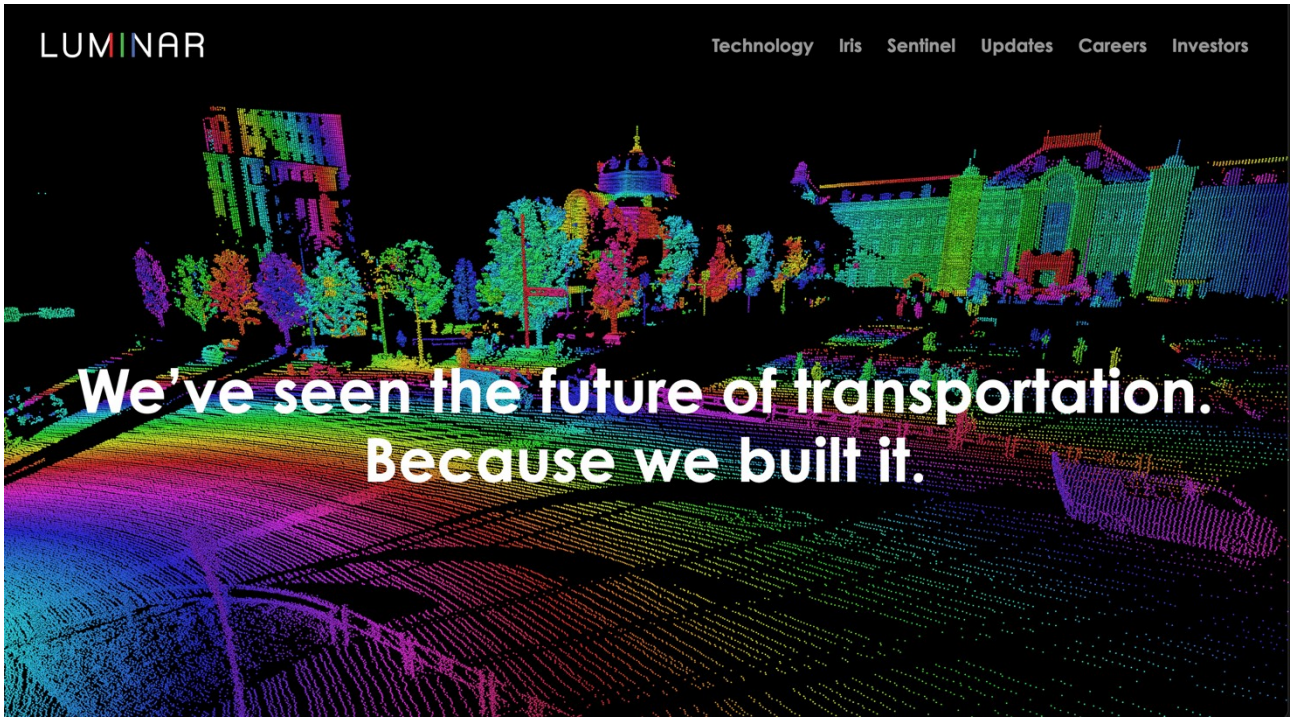
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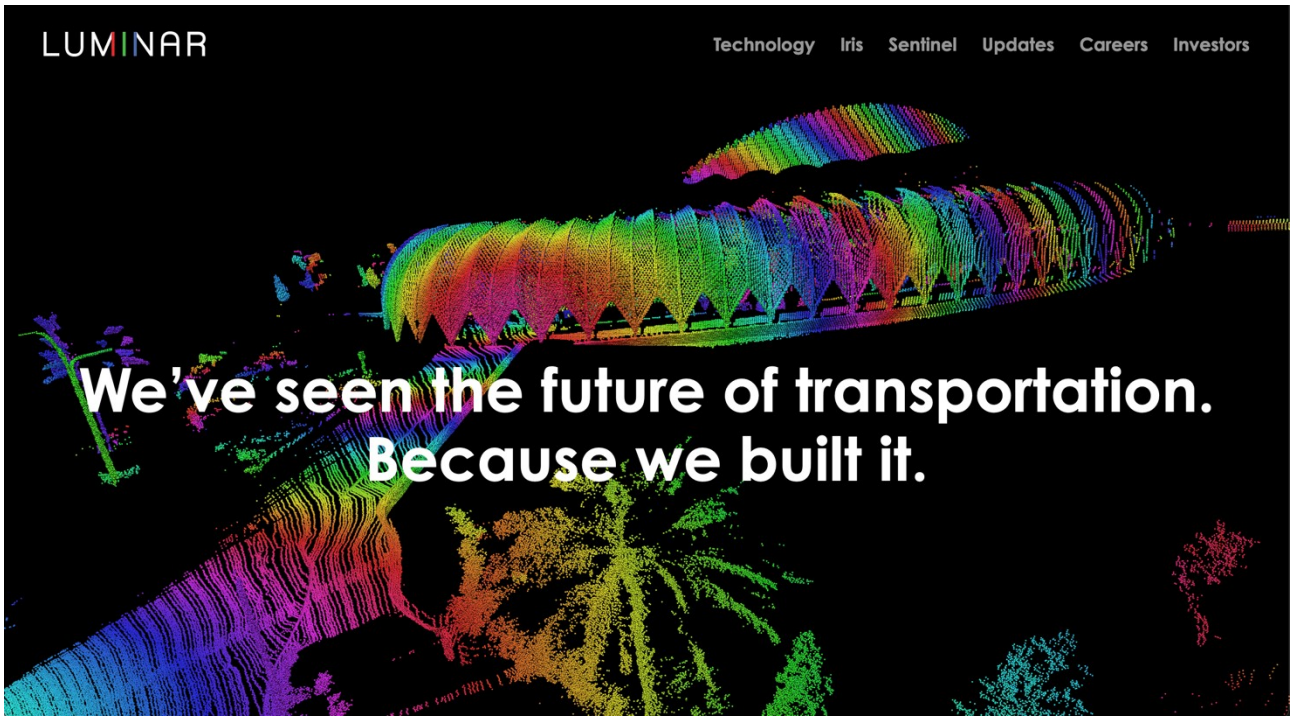
34. Lumentum (USA), < https://www.lumentum.com/en>

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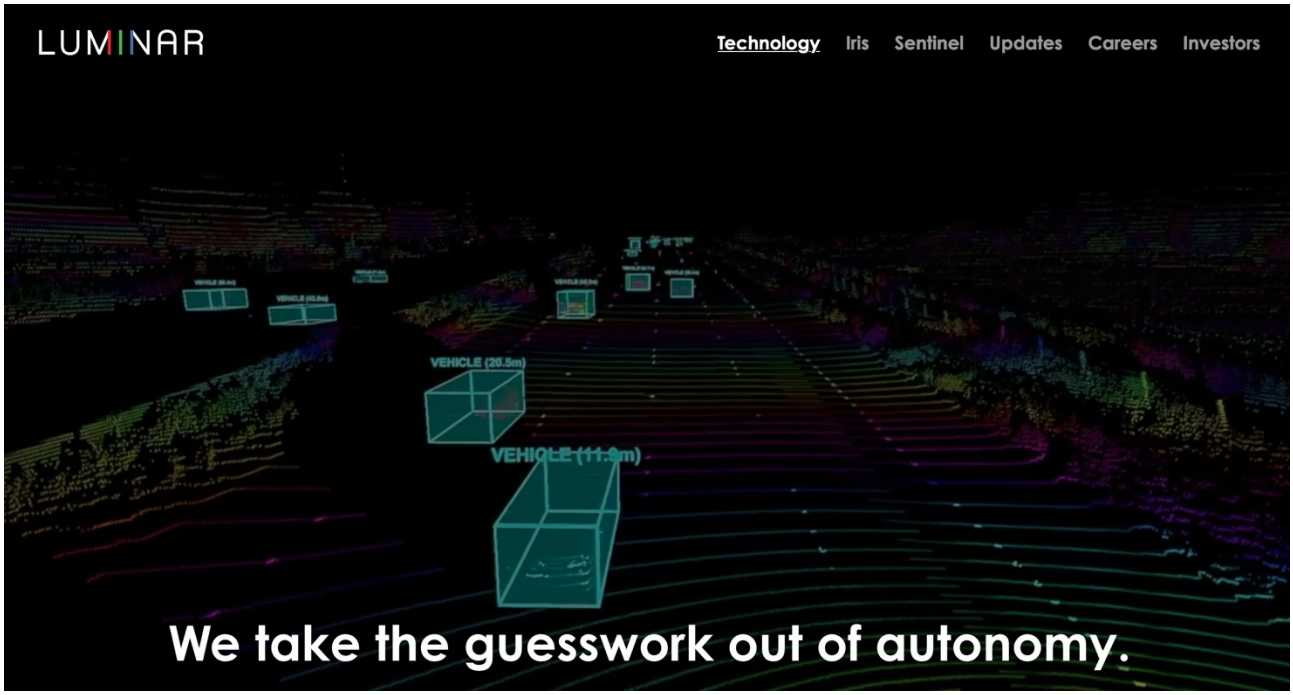
35. Luminartech (USA), <https://www.luminartech.com/>

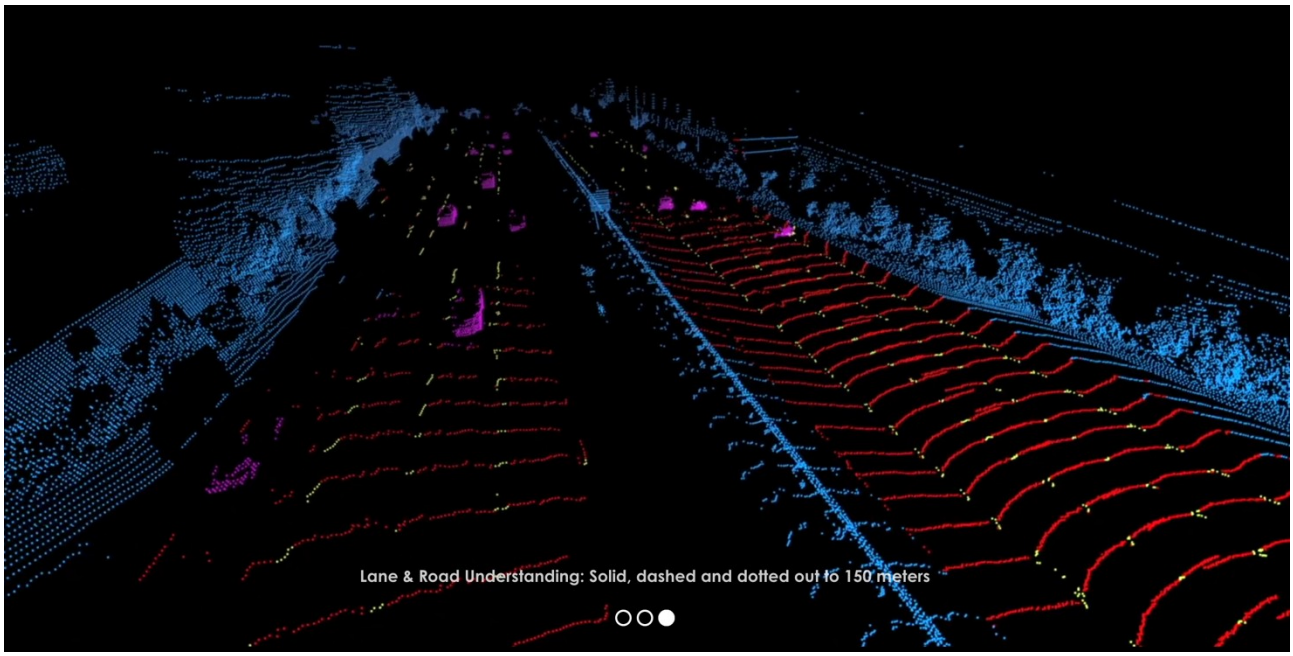
Source: <https://www.luminartech.com/>





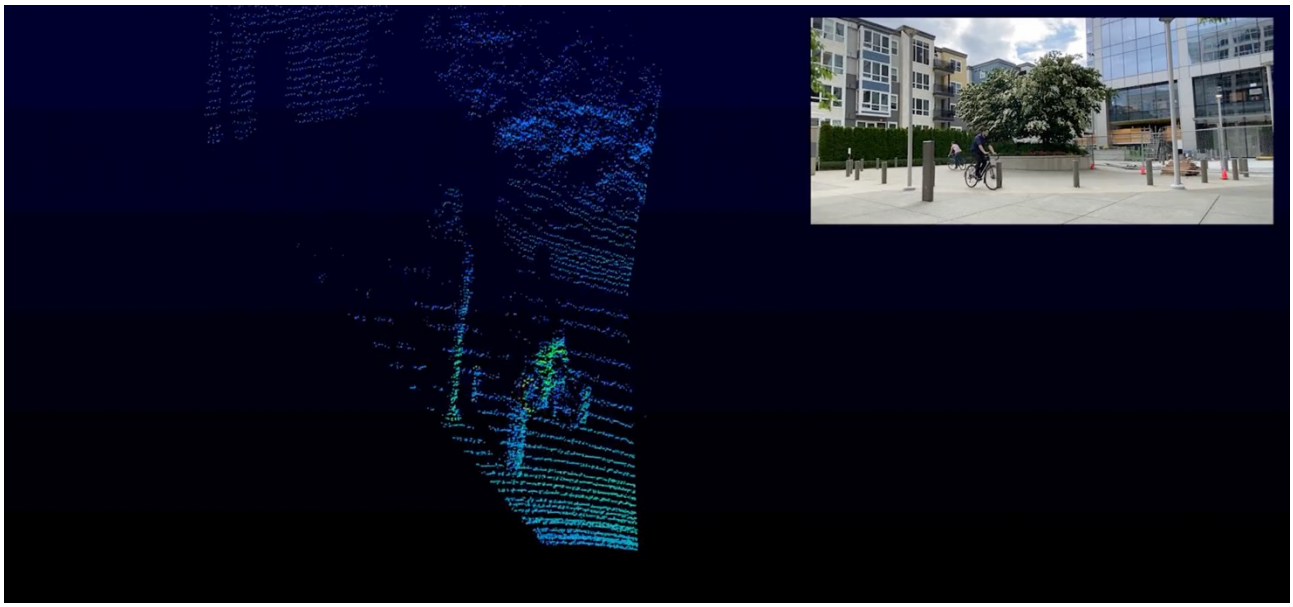
Source: < https://www.luminartech.com/technology/>

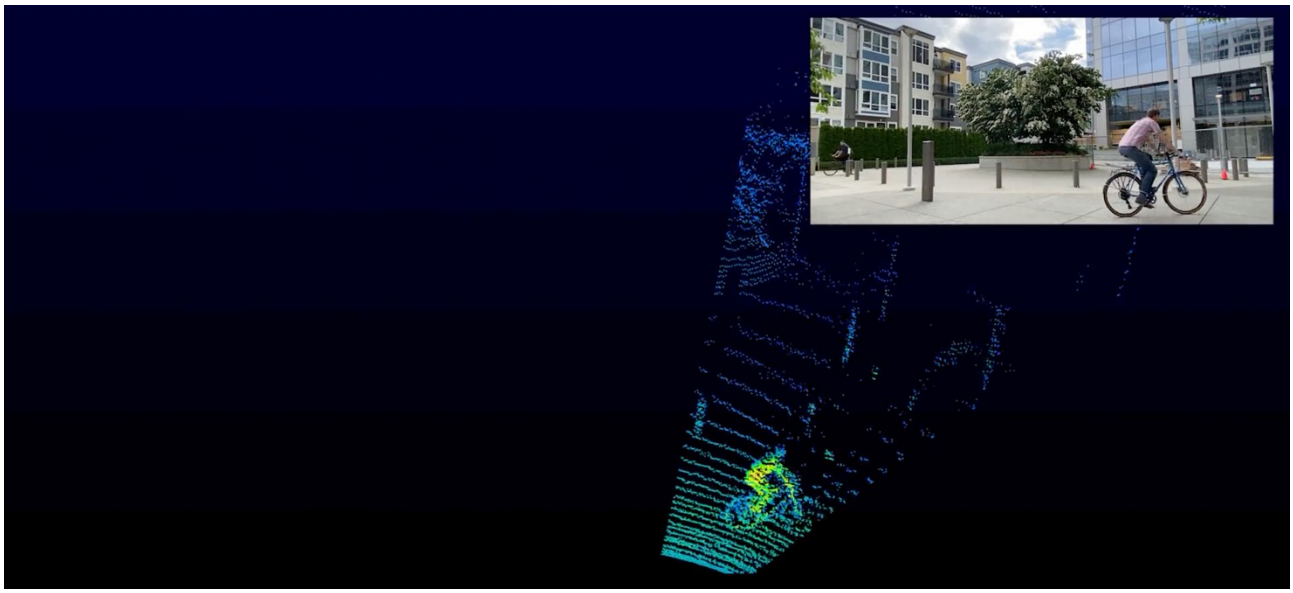




36. Lumotive (USA), <https://www.lumotive.com/>

Source: < https://www.lumotive.com/technology>



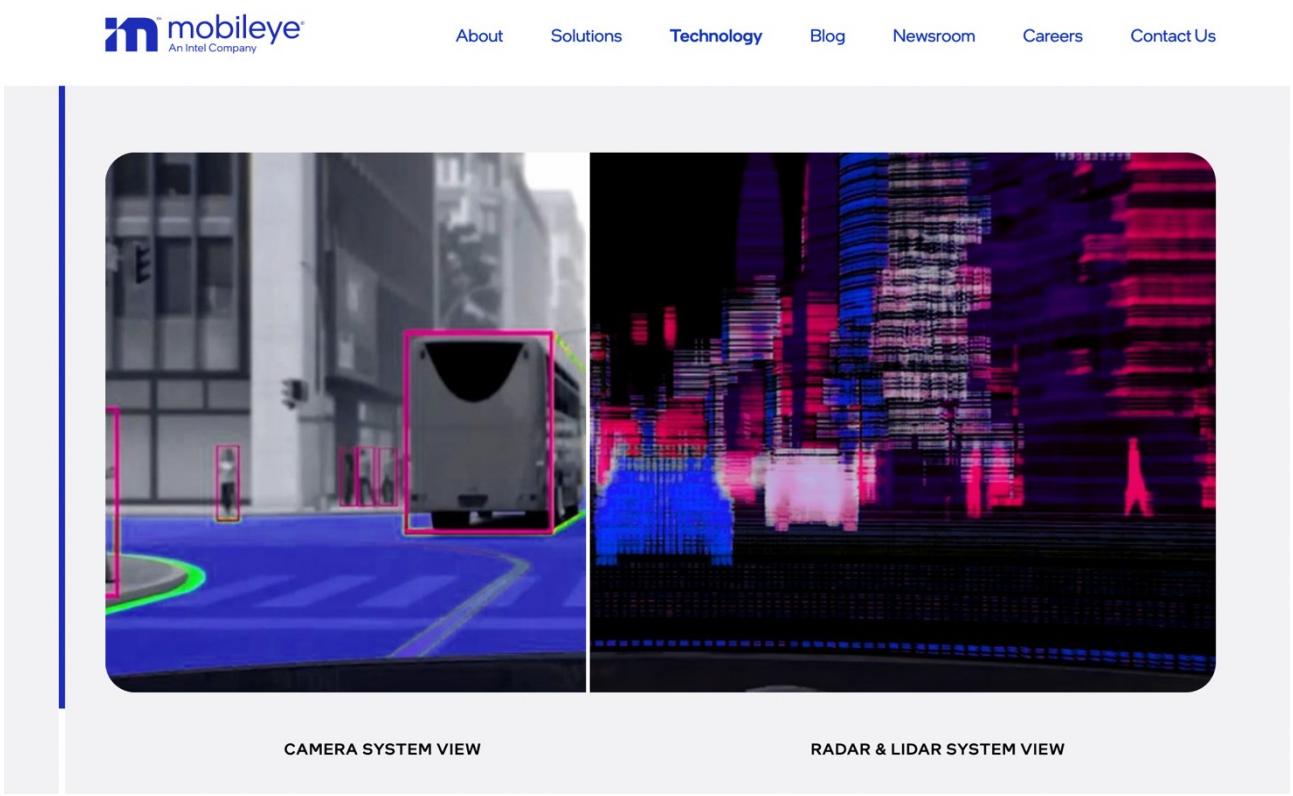


37. Lyft Autonomous (USA), < https://autonomous.lyft.com/>

No images available.

38. Mobileye (Israel), <https://www.mobileye.com/>

Source: < https://www.mobileye.com/technology/>

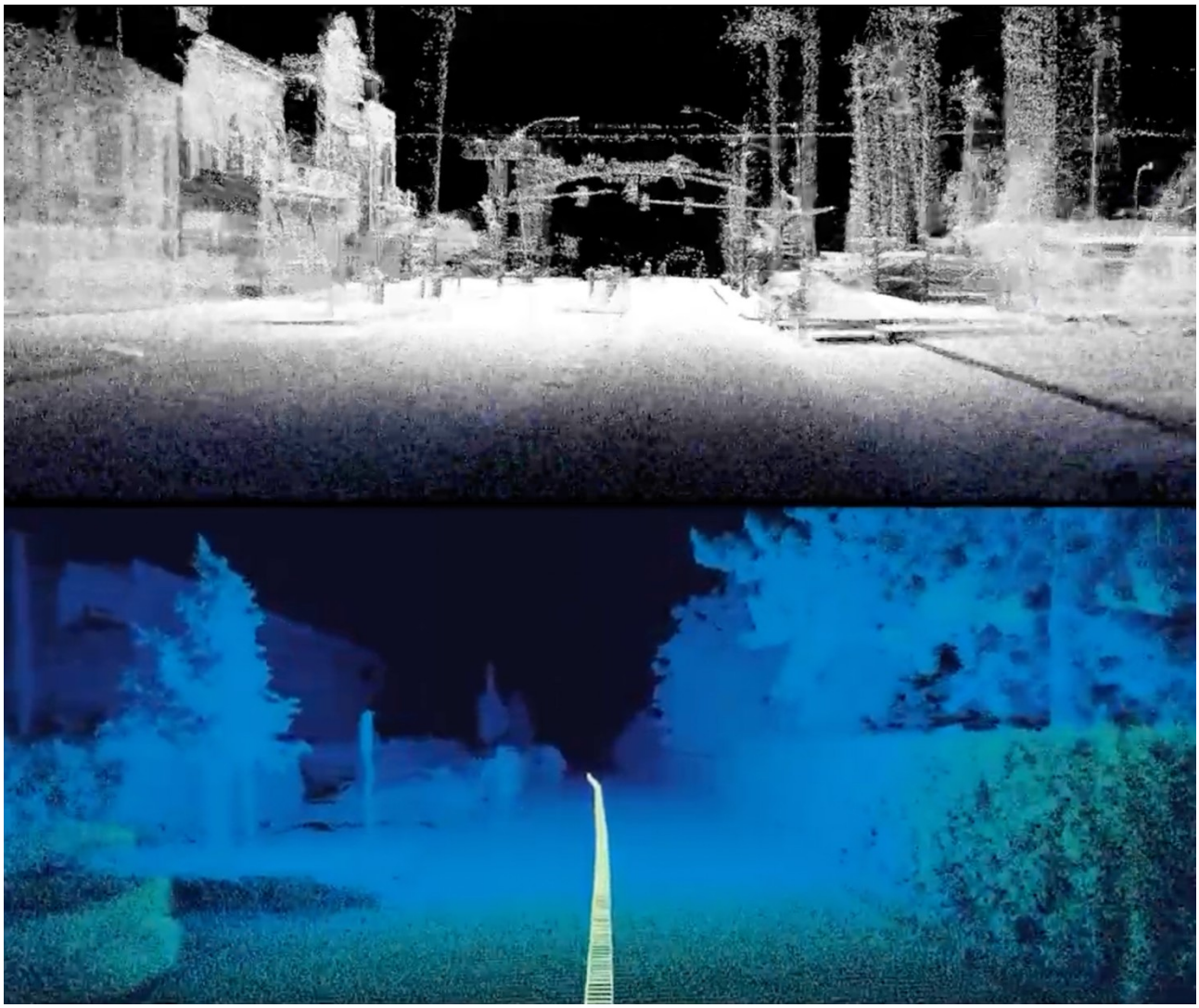


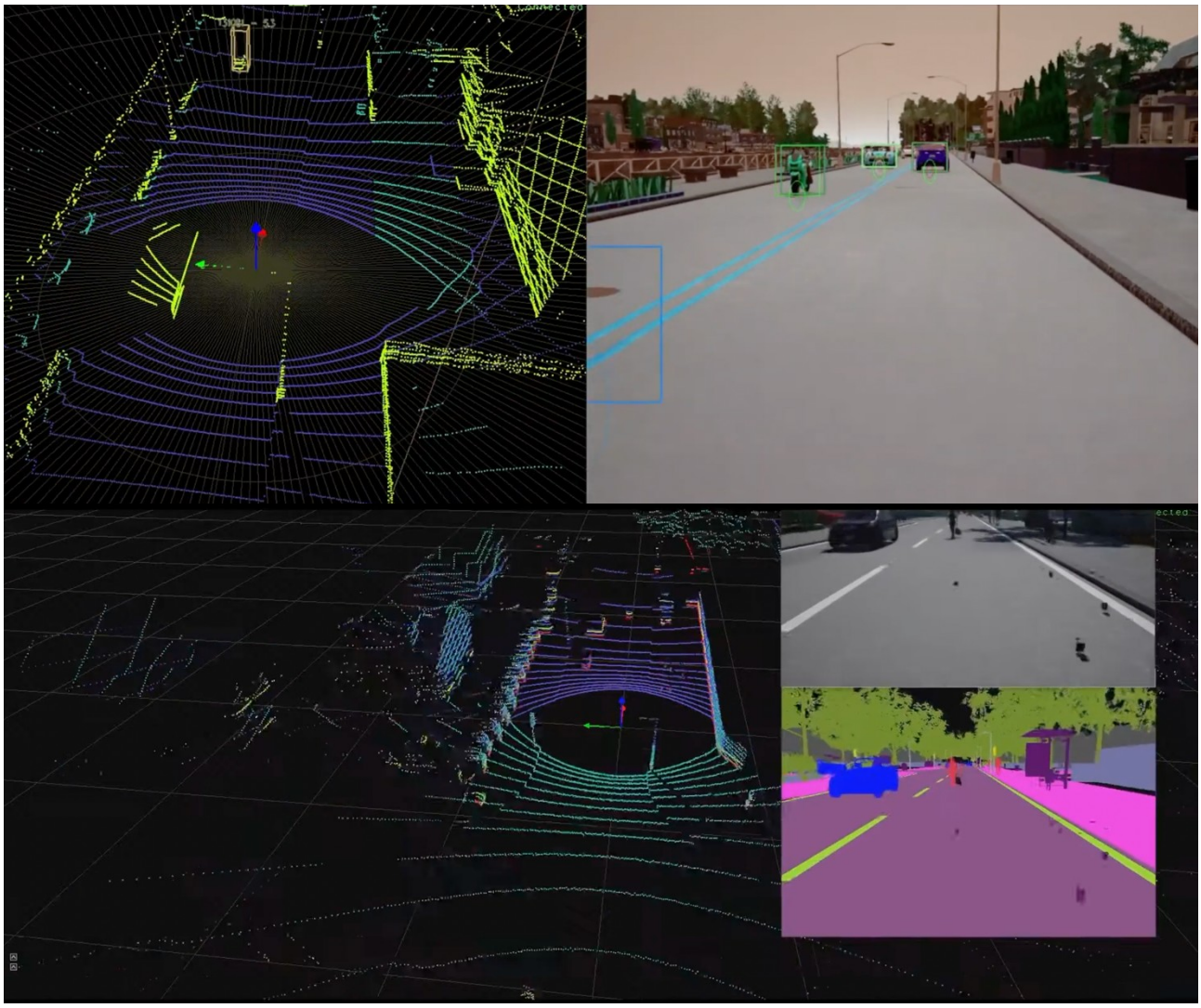
Source: < https://www.mobileye.com/technology/true-redundancy/>



39. Navya (France), <https://navya.tech/en>

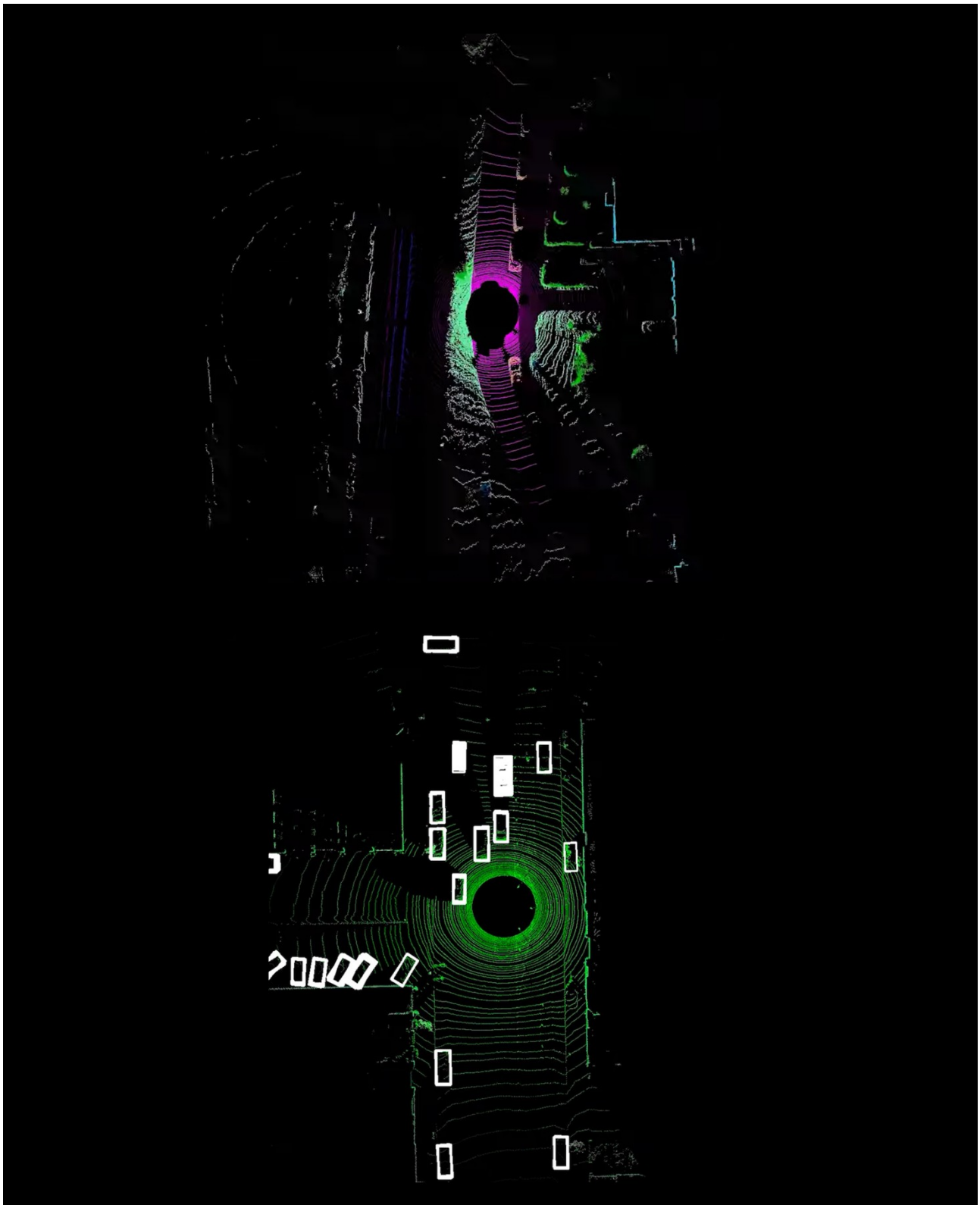
Source: < https://navya.tech/en/technology/software/>

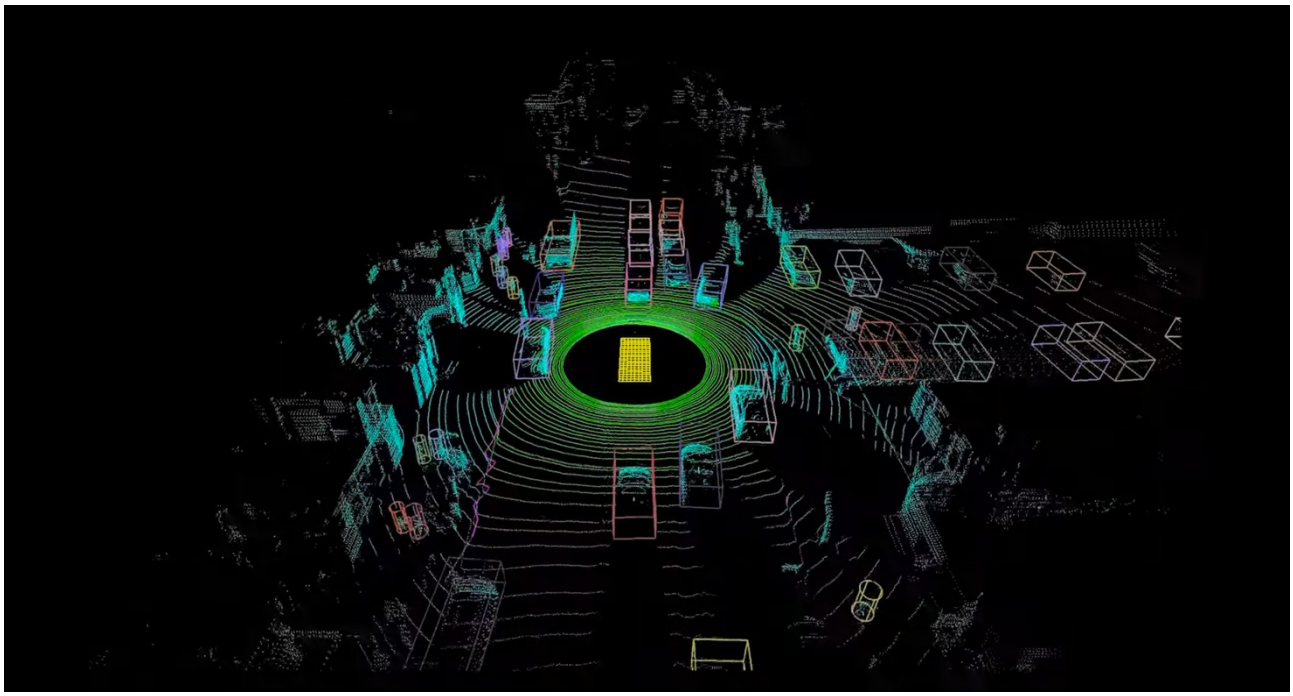




40. NVIDIA Drive (USA), <https://developer.nvidia.com/drive>

Source: <https://www.nvidia.com/en-us/self-driving-cars/drive-videos/>





41. Omnivision (USA), https://www.ovt.com/

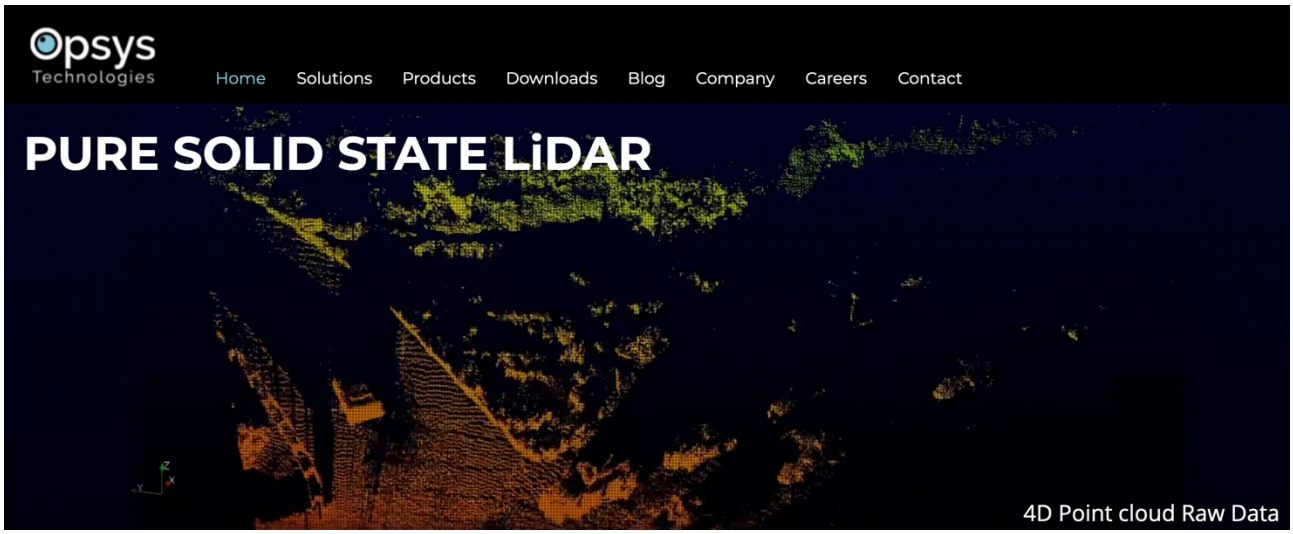
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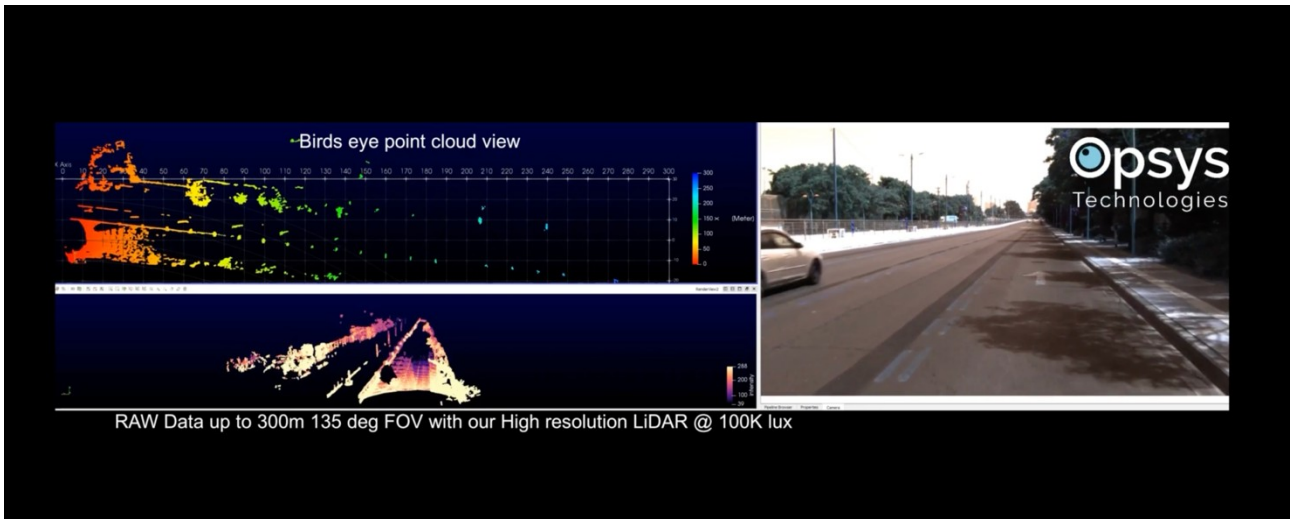
42. Onsemi (USA), https://www.onsemi.com/

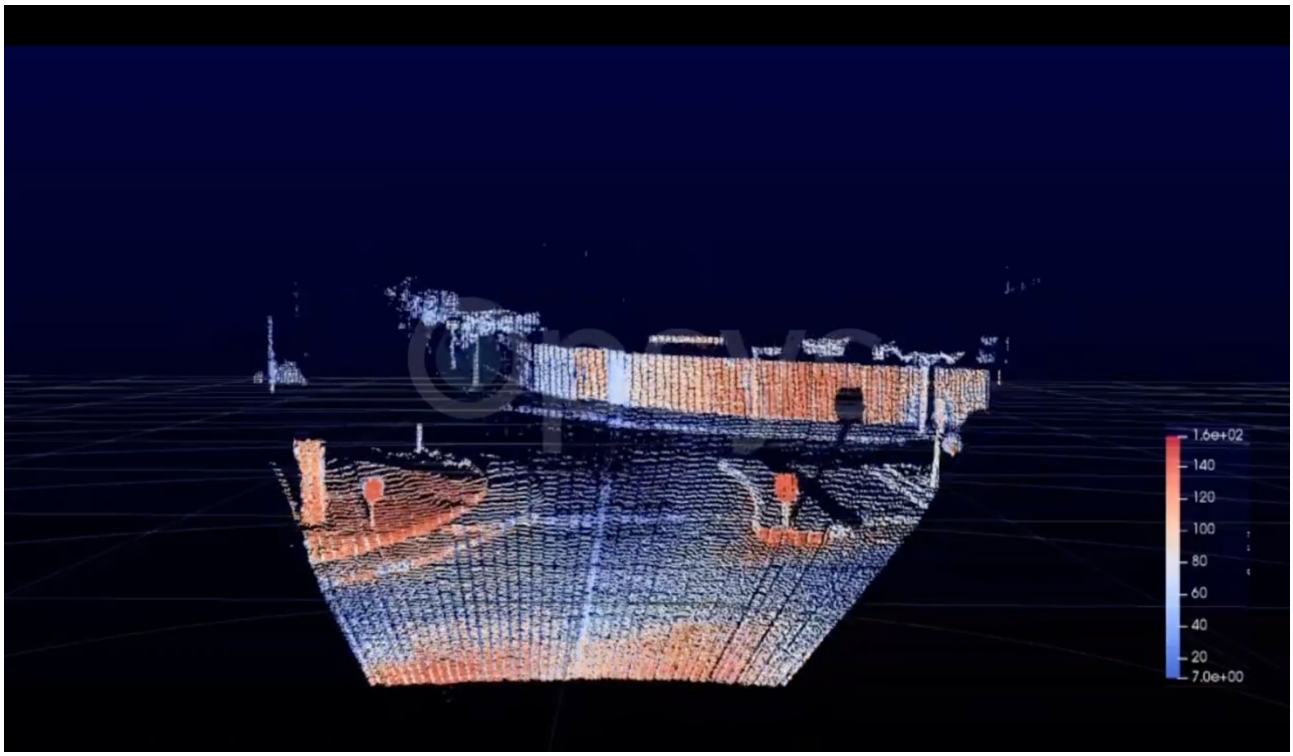
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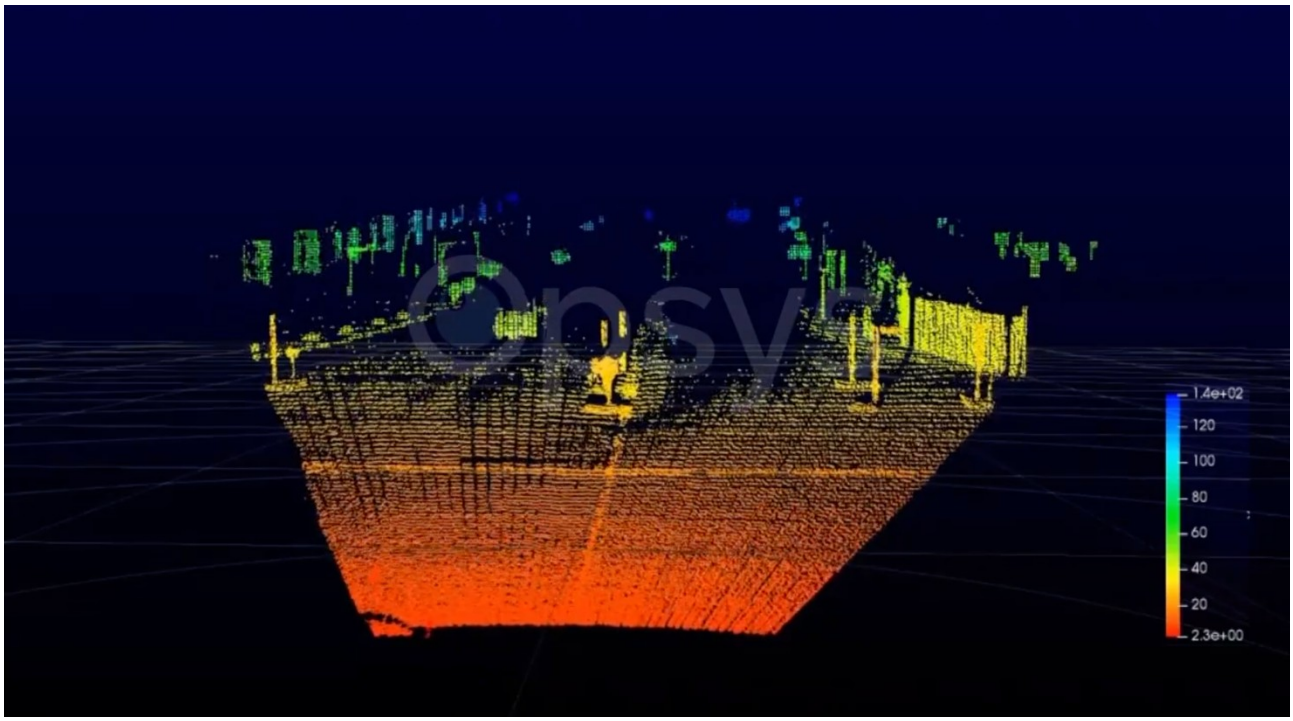
43. Opsys (Israel), < https://www.opsys-tech.com/>

Source: https://www.opsys-tech.com/




Birds eye point cloud view
Opsys
Technologies
RAW Data up to 300m 135 deg FOV with our High resolution LiDAR @ 100K lux


1.6e+02
140
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7.0e+00



44. Orbit (Belgium), < https://orbitgt.com/>

Source: < https://orbitgt.com/cases/road-management-bern/>

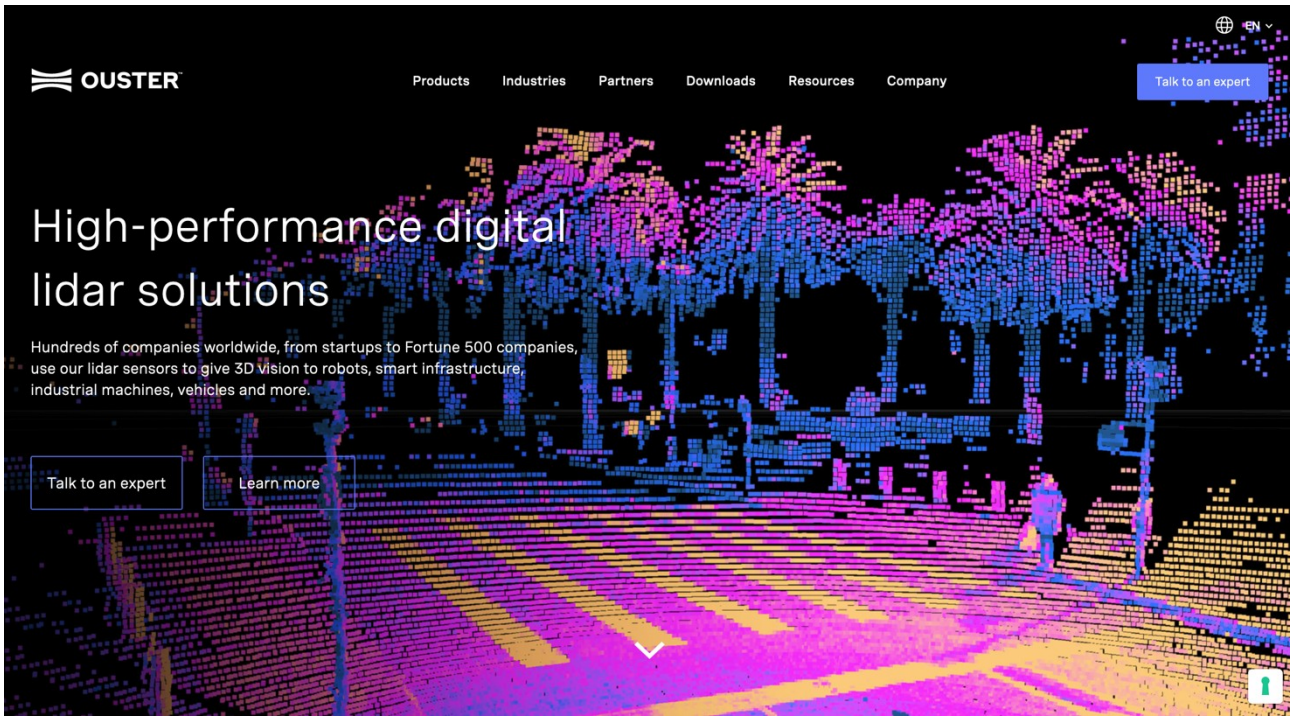


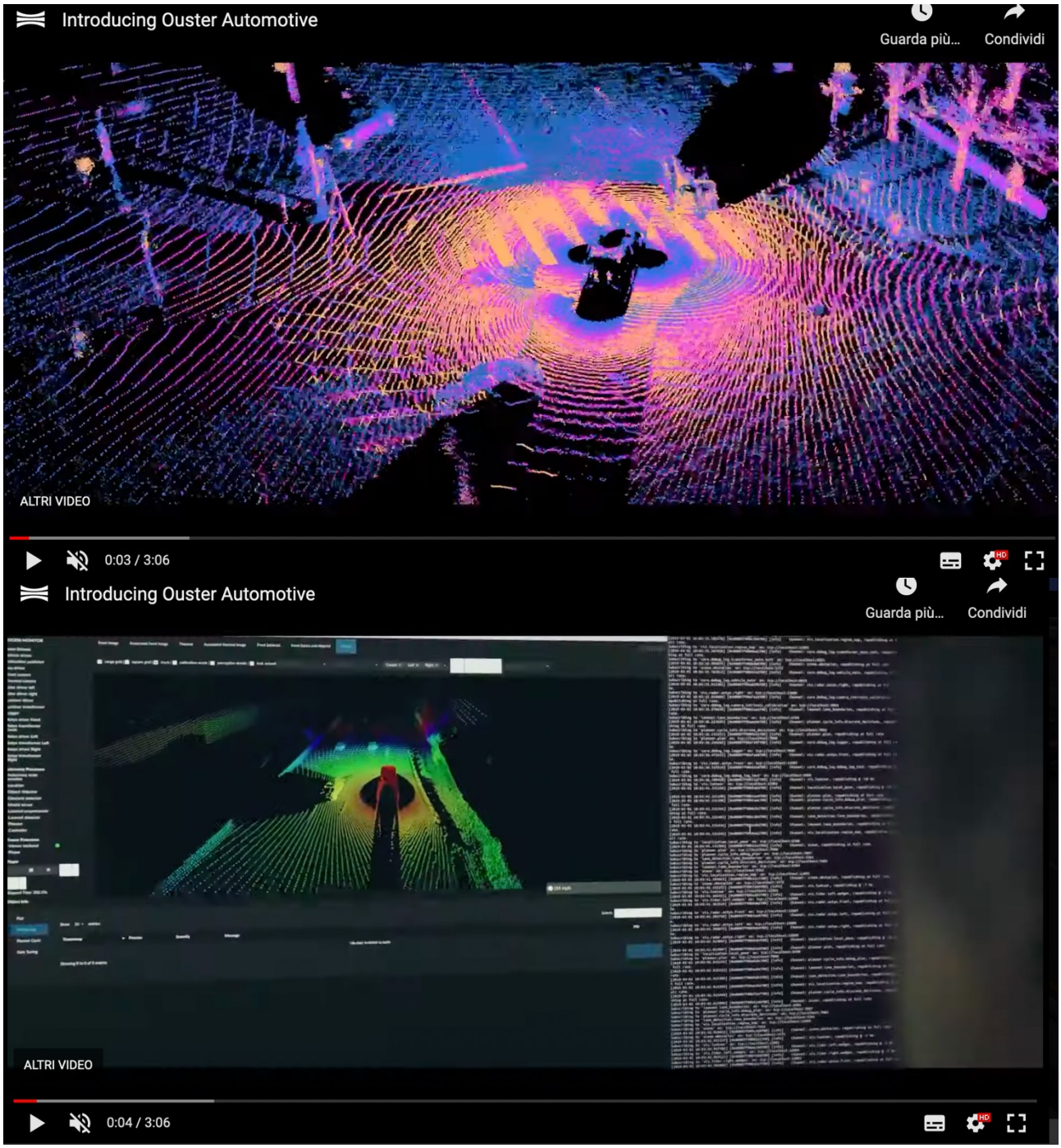
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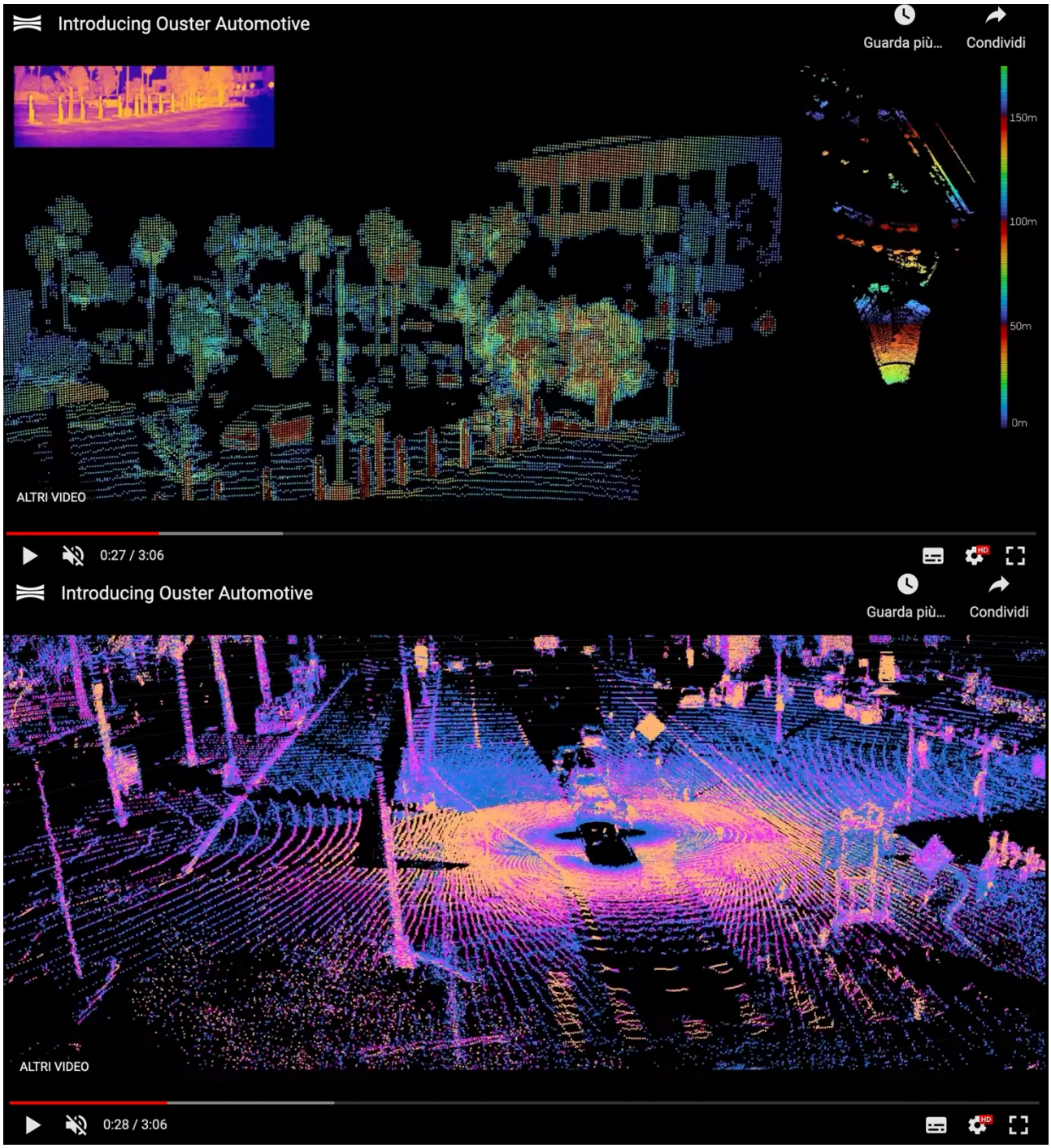


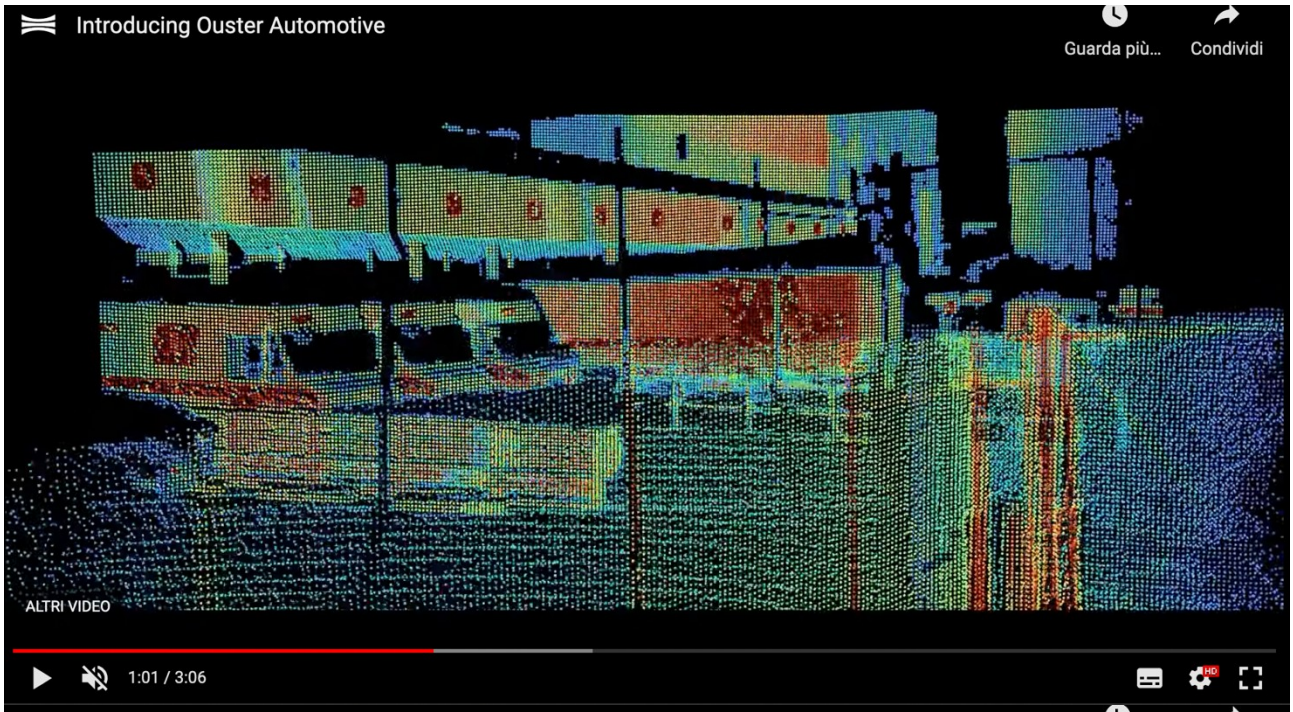
45. Ouster (USA), https://ouster.com/

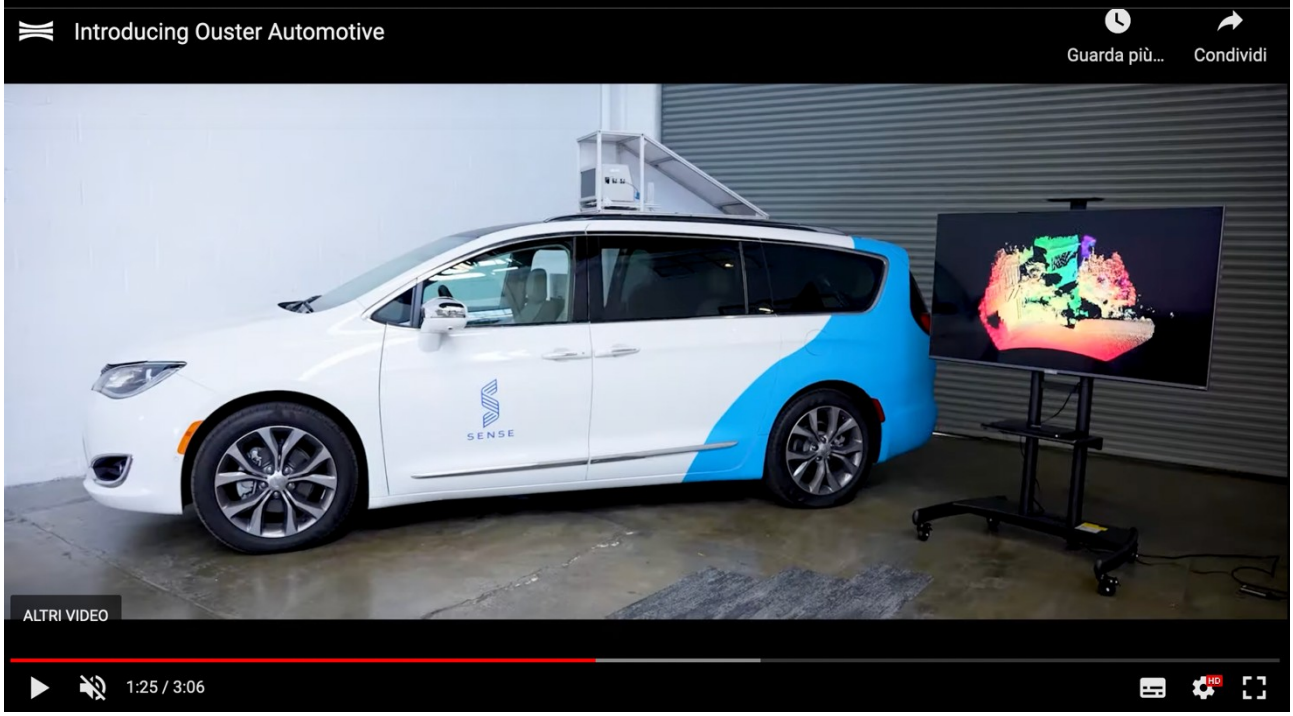
Source; https://ouster.com

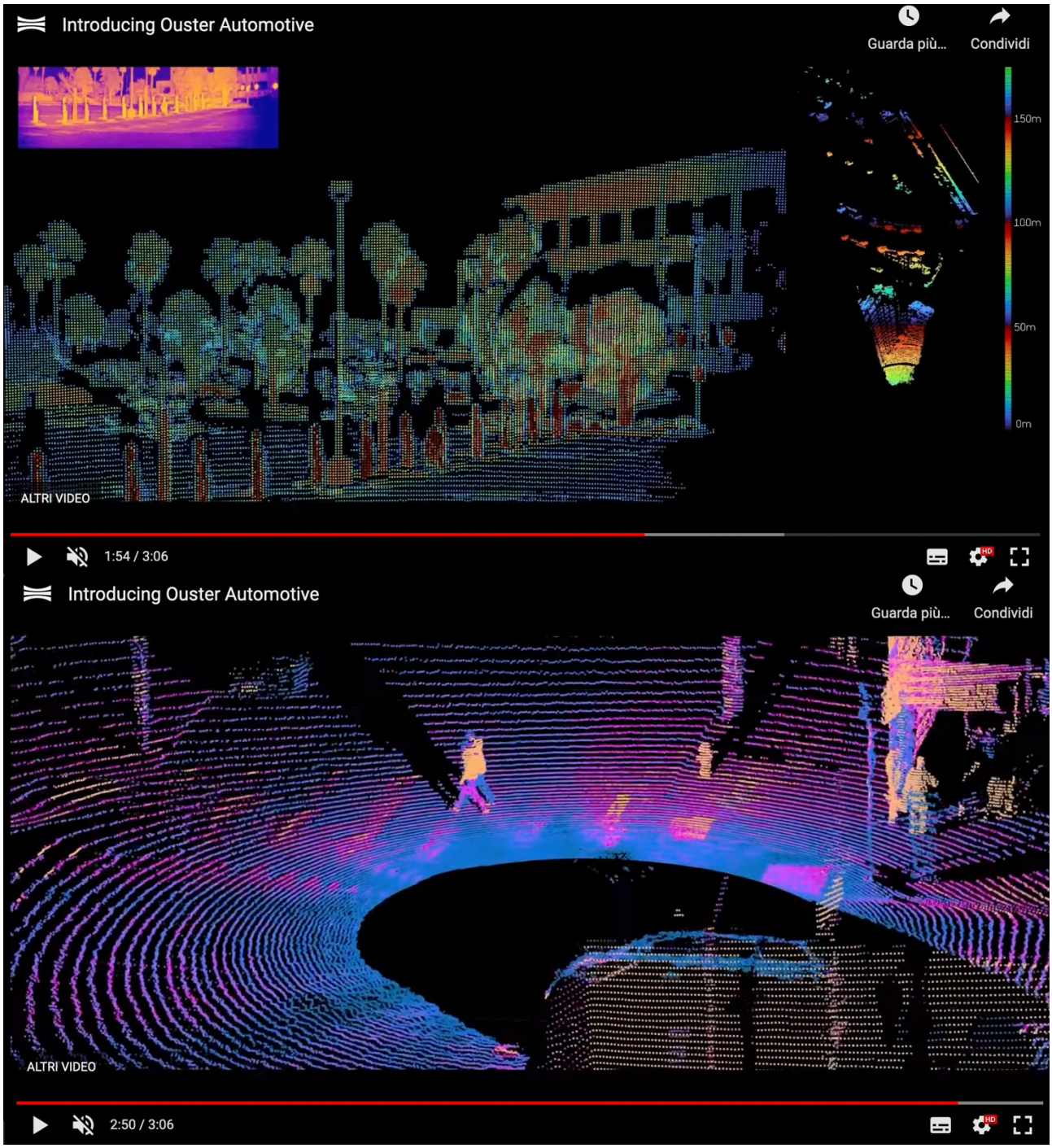



Introducing Ouster Automotive
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Introducing Ouster Automotive
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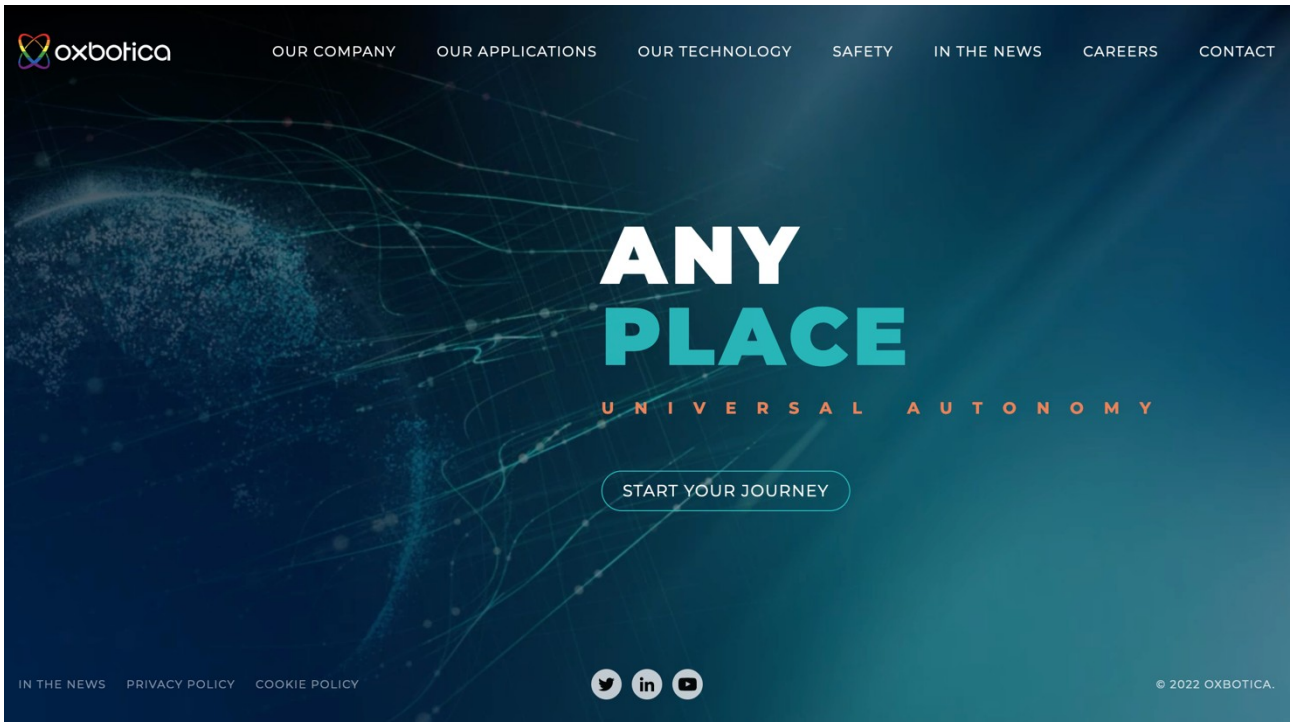

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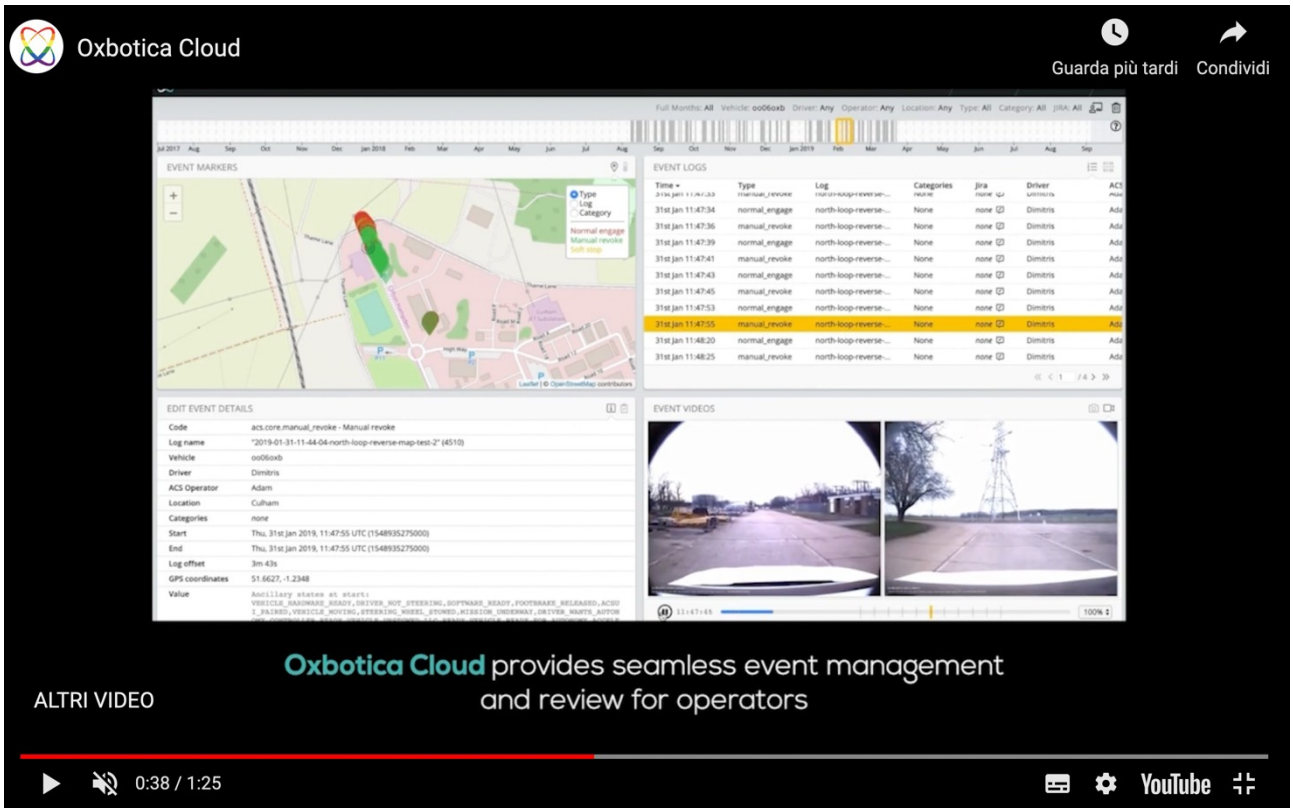


46. Oxbotica (UK), <https://www.oxbotica.com/>

Source: <https://www.oxbotica.com/>



Source: < https://www.oxbotica.com/our-technology/>



Oxbotica MetaDriver

Oxbotica MetaDriver dramatically reduces the time and cost of verification and validation, accelerating our customers' route to safe and accurate AV functionality. By harnessing AI and onboard data to synthesize simulated scenarios with real-world driving miles, MetaDriver is capable of validating most of a customer's environment without driving an actual vehicle in it.

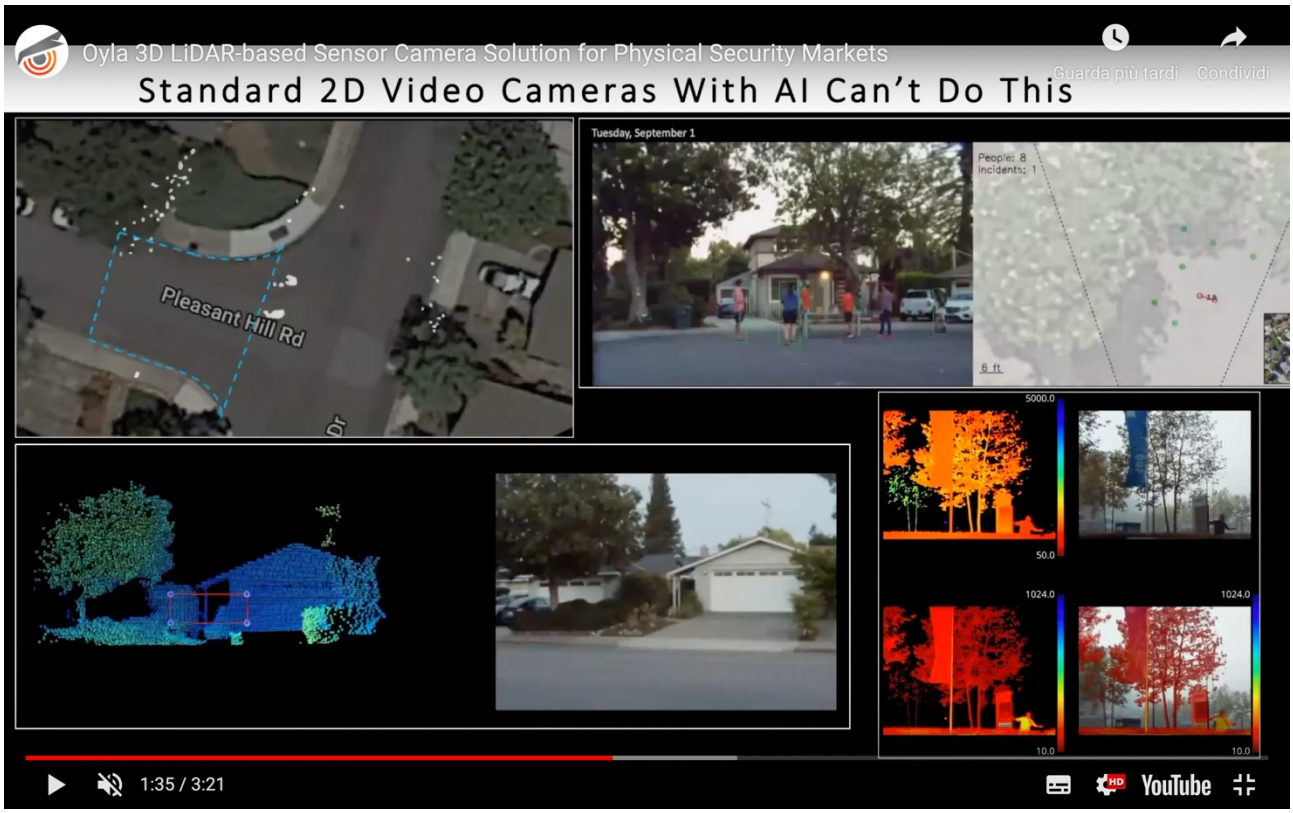


47. Oyla (USA), https://oyla.ai/

Source: https://oyla.ai/

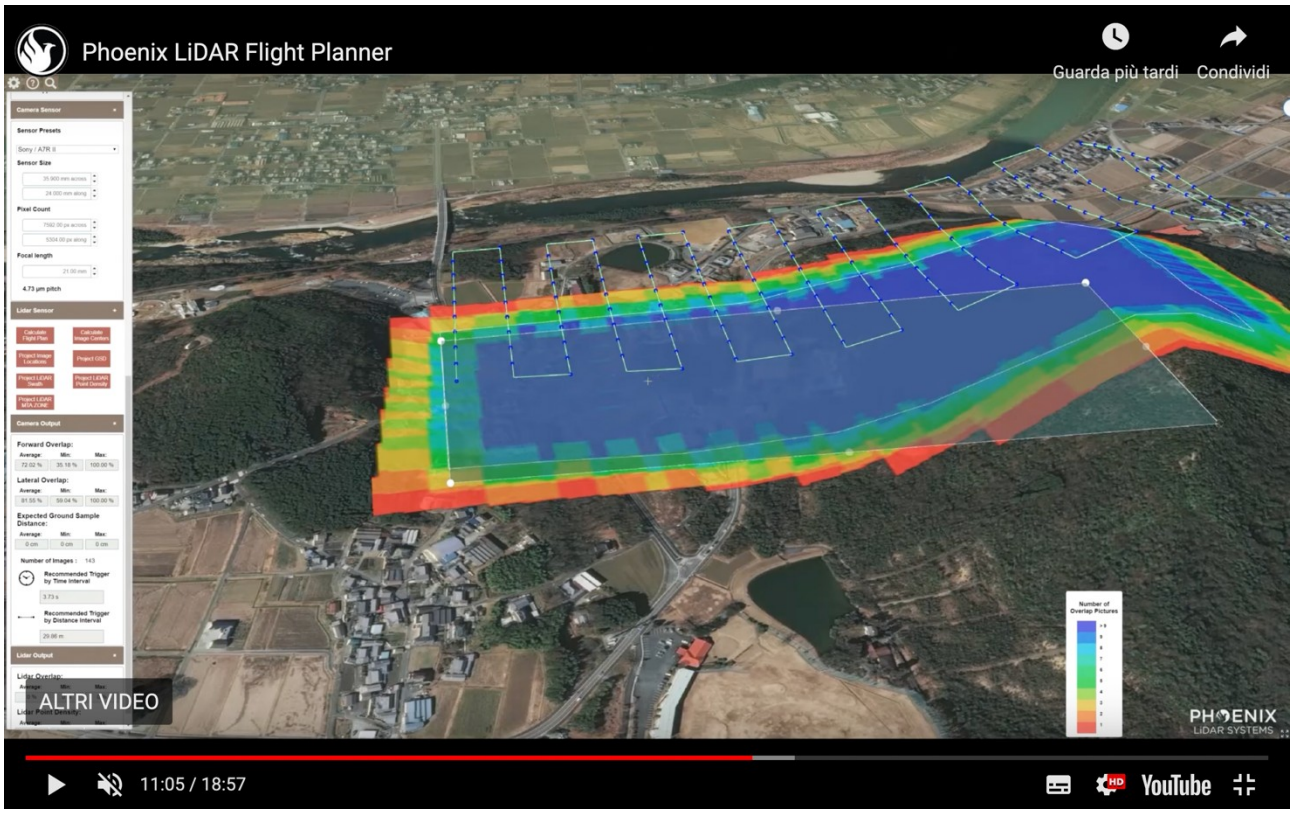




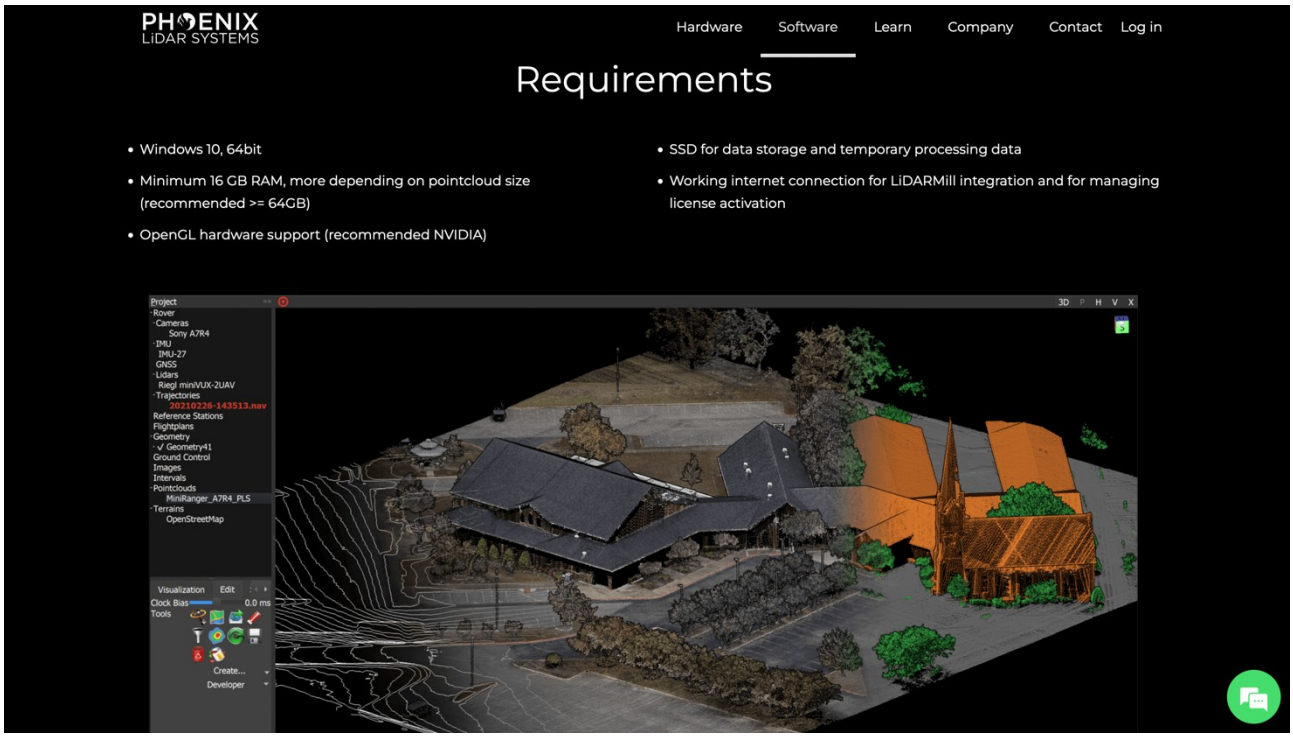


48. PhoenixLidar (USA), https://www.phoenixlidar.com/

Source: <https://www.phoenixlidar.com/flightplan/>

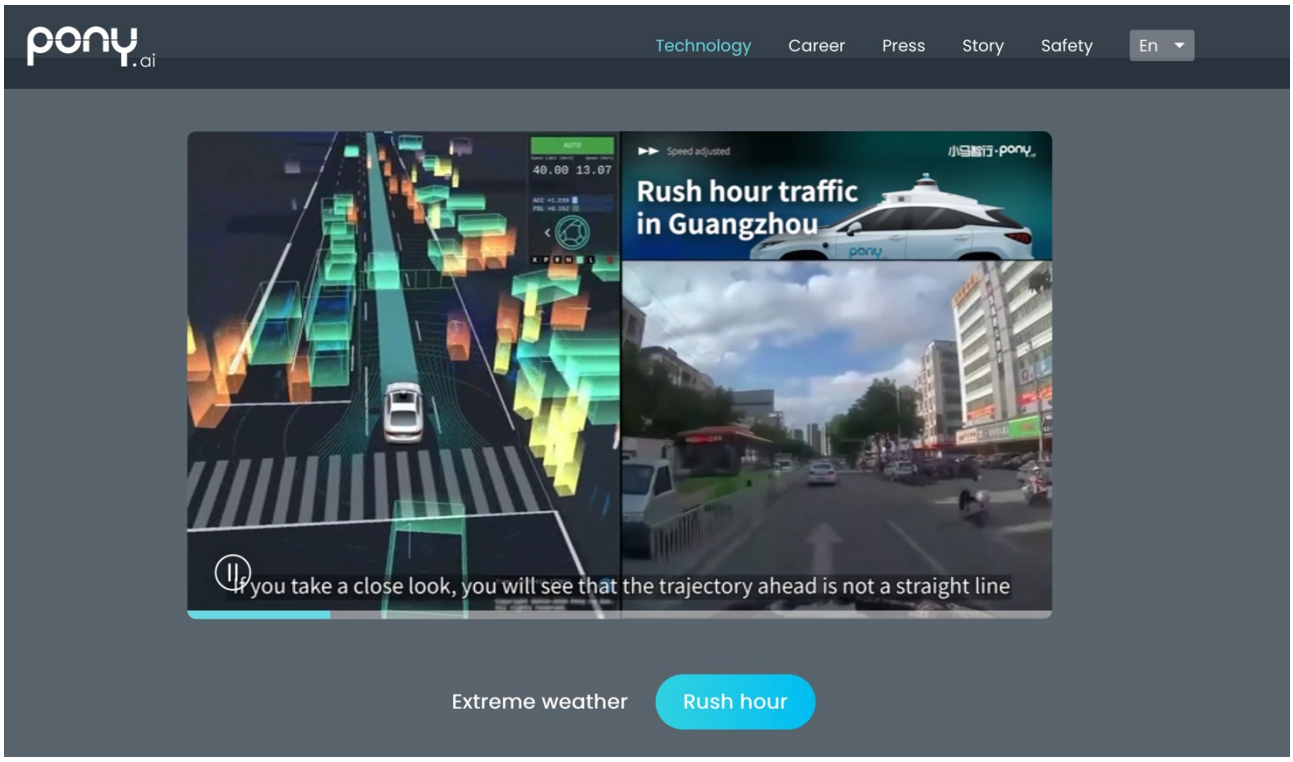


Source: https://www.phoenixlidar.com/software/



49. Pony Ai (USA), https://pony.ai/

Source: https://pony.ai/tech?lang=en



50. Preact (USA), https://www.preact-tech.com/

Source: https://www.preact-tech.com/

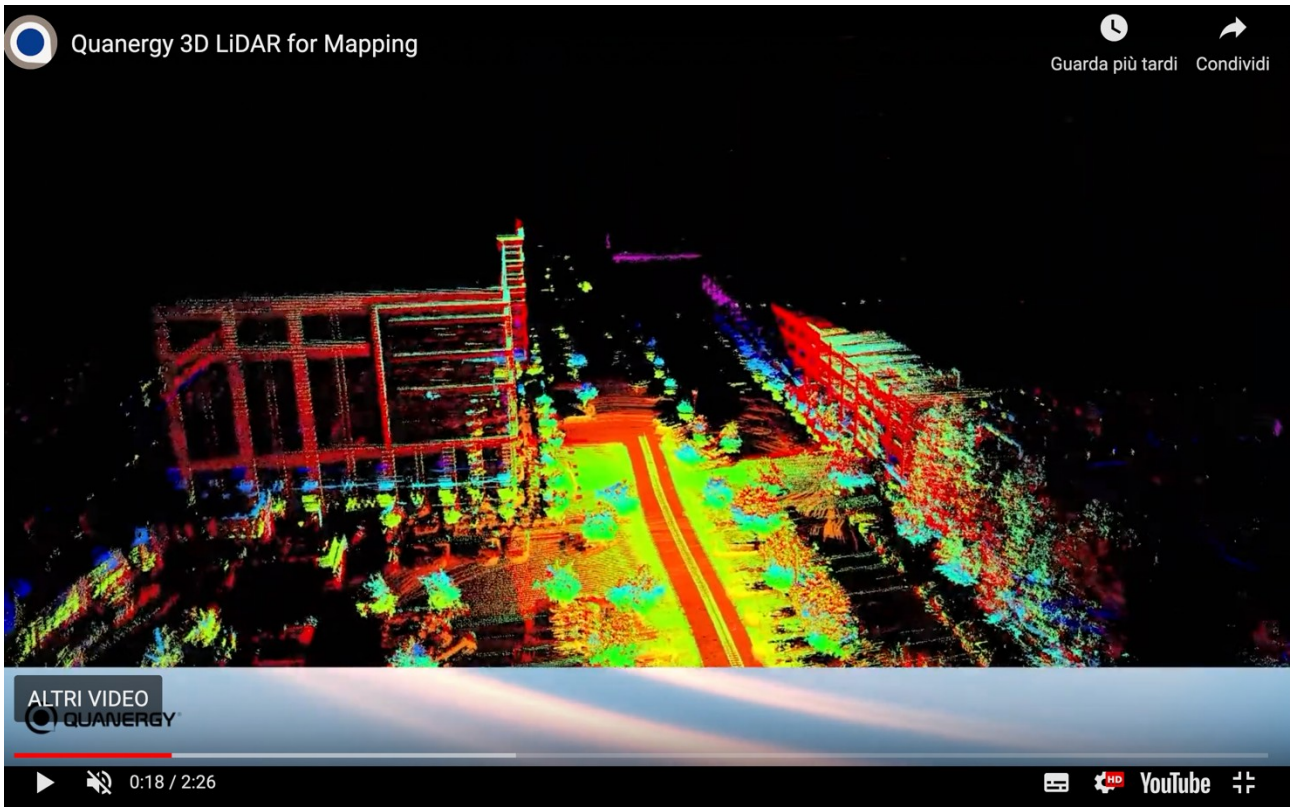


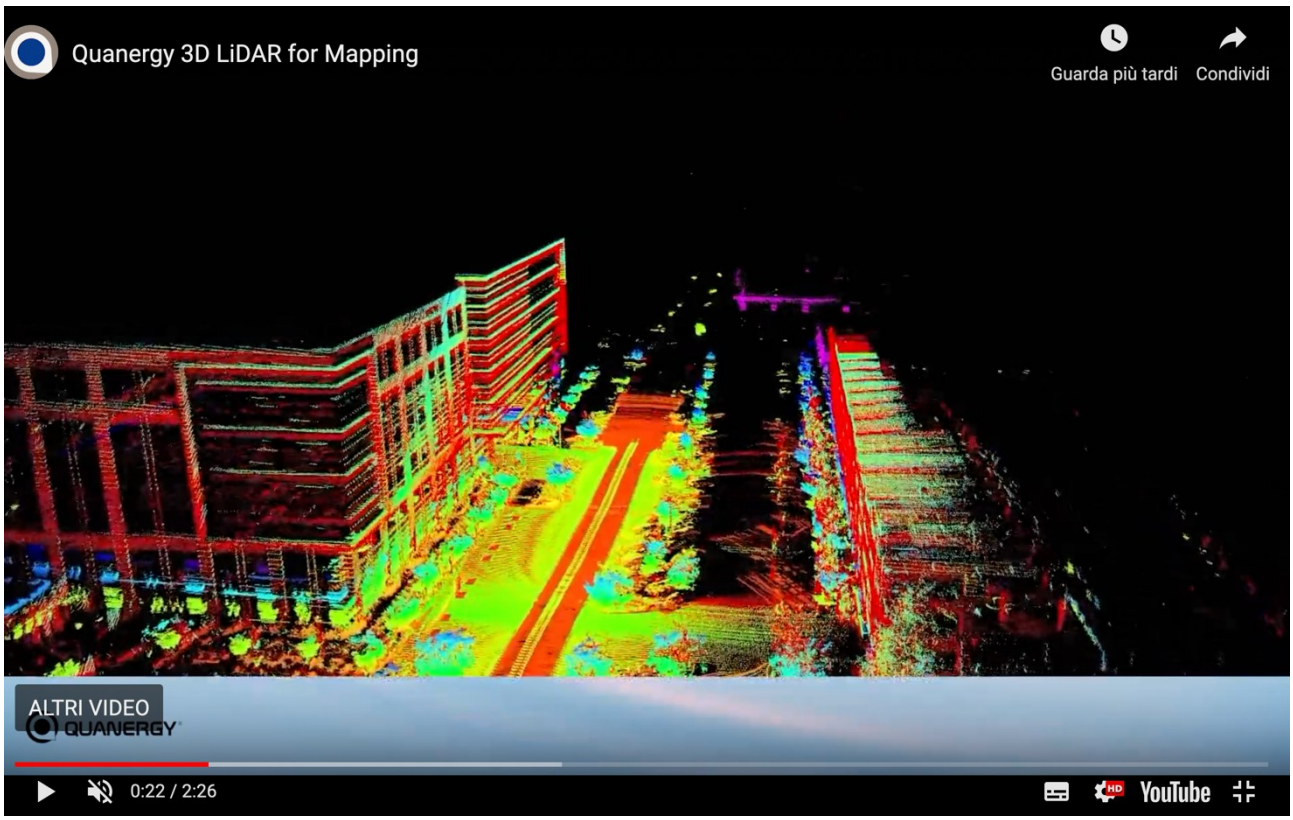
51. Princeton Lightwave

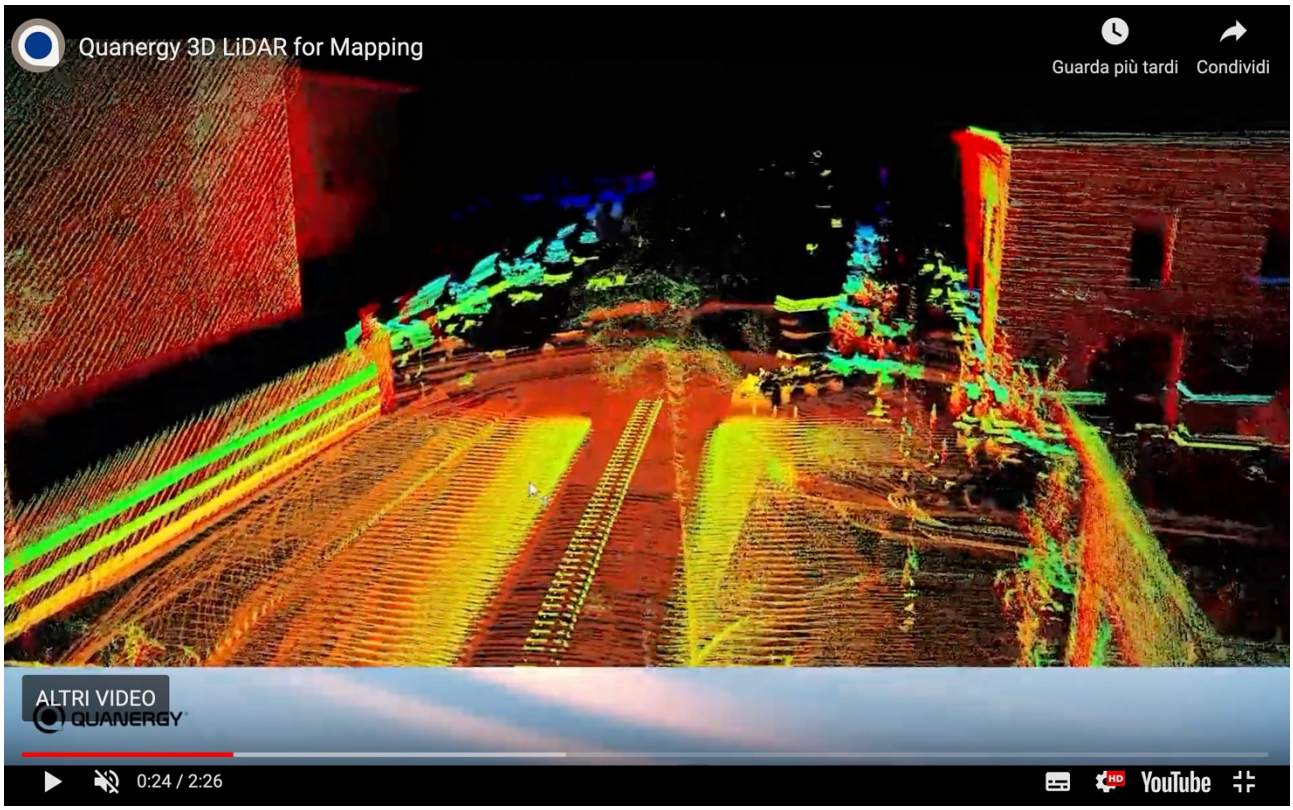
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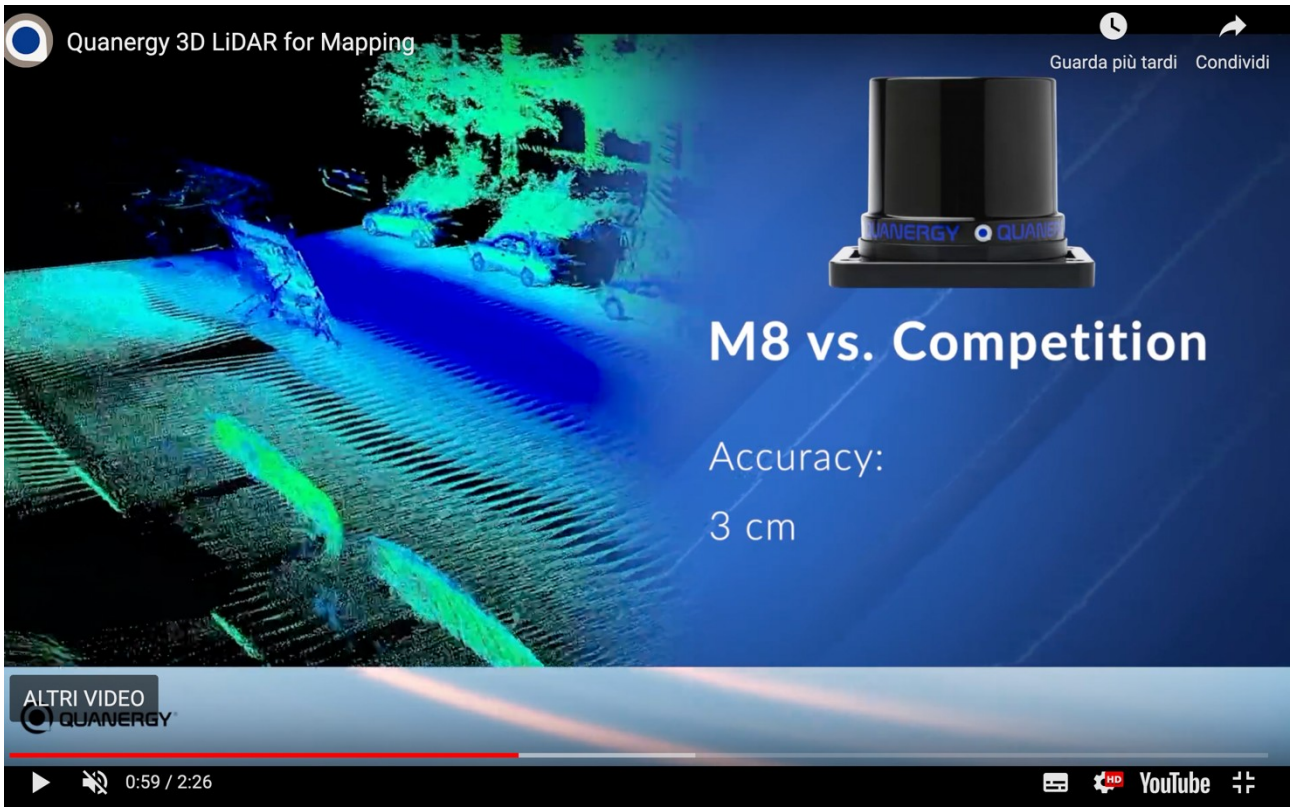
52. Quanergy (USA), https://quanergy.com/

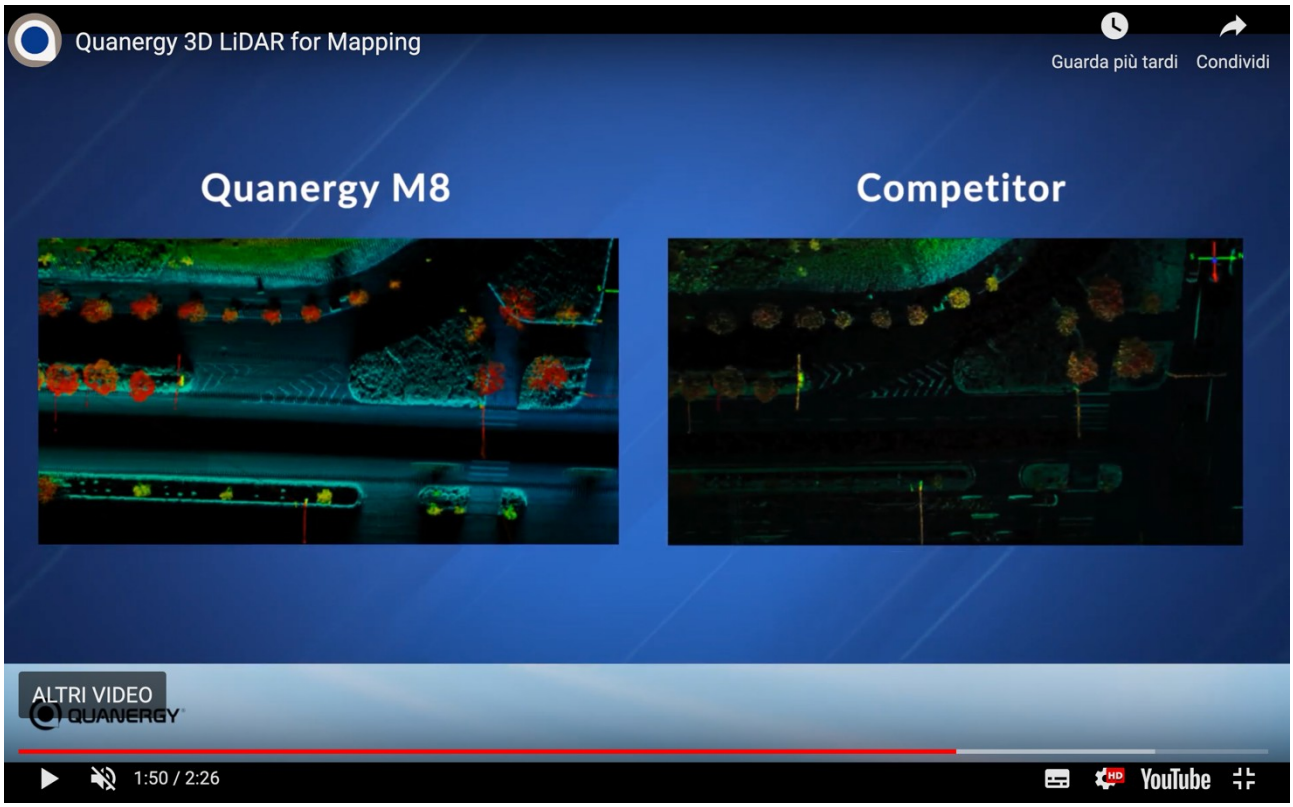
Source: <https://quanergy.com/applications/mapping/>

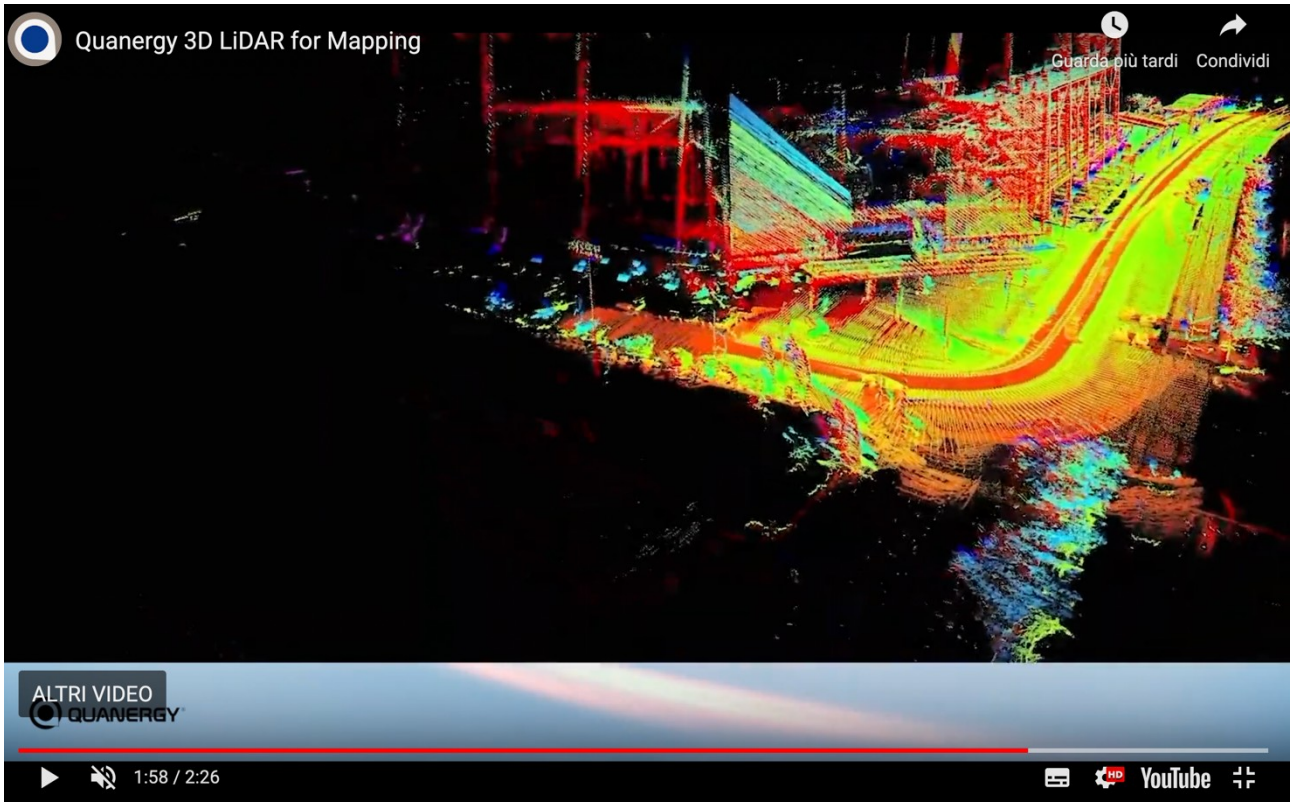





Quanergy 3D LiDAR for Mapping
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QUANERGY
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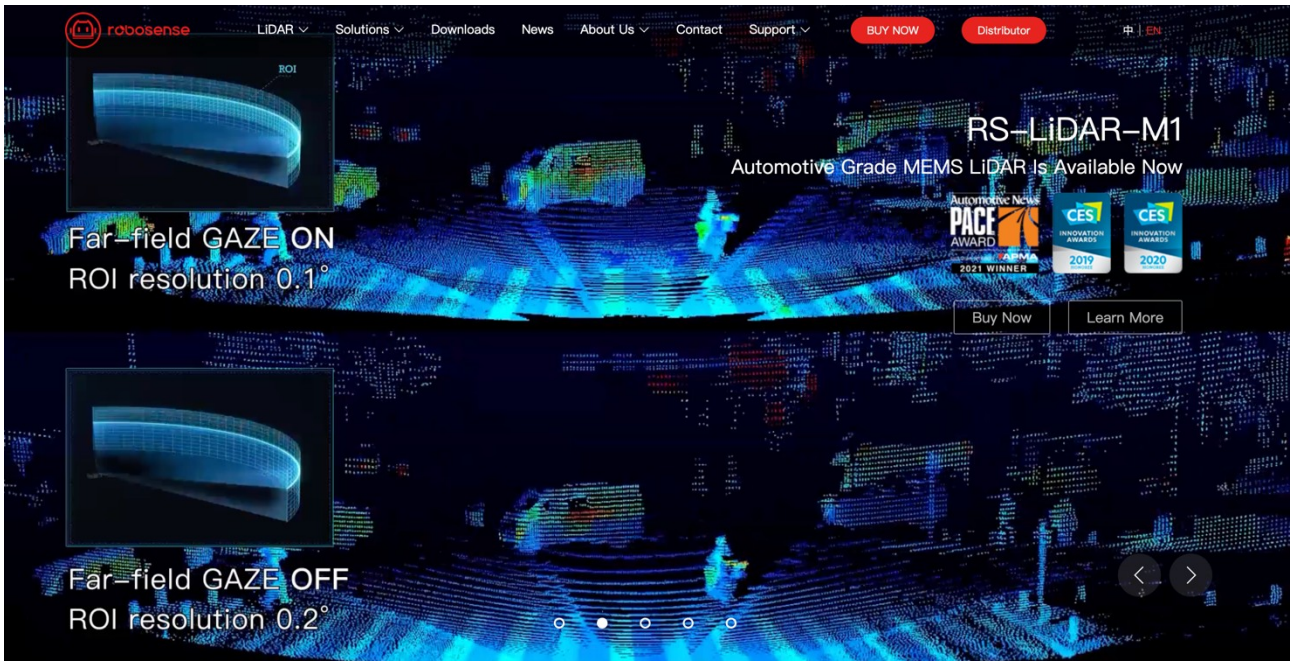

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M8 vs. Competition
Accuracy:
3 cm
ALTRI VIDEO
QUANERGY
0:59 / 2:26
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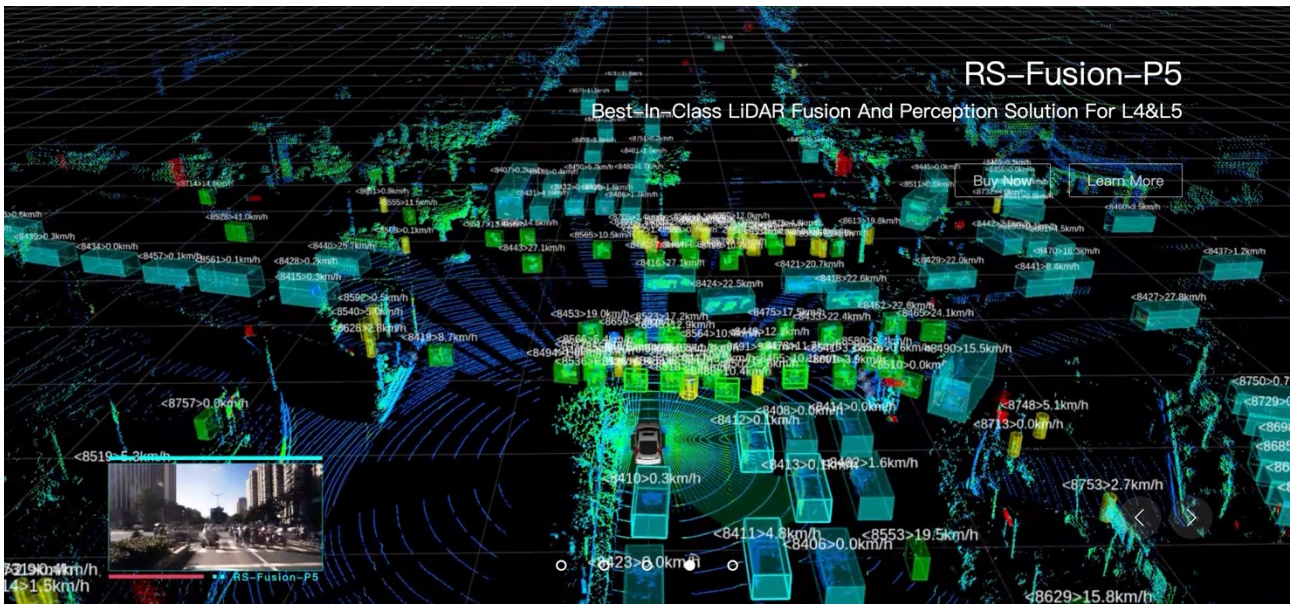


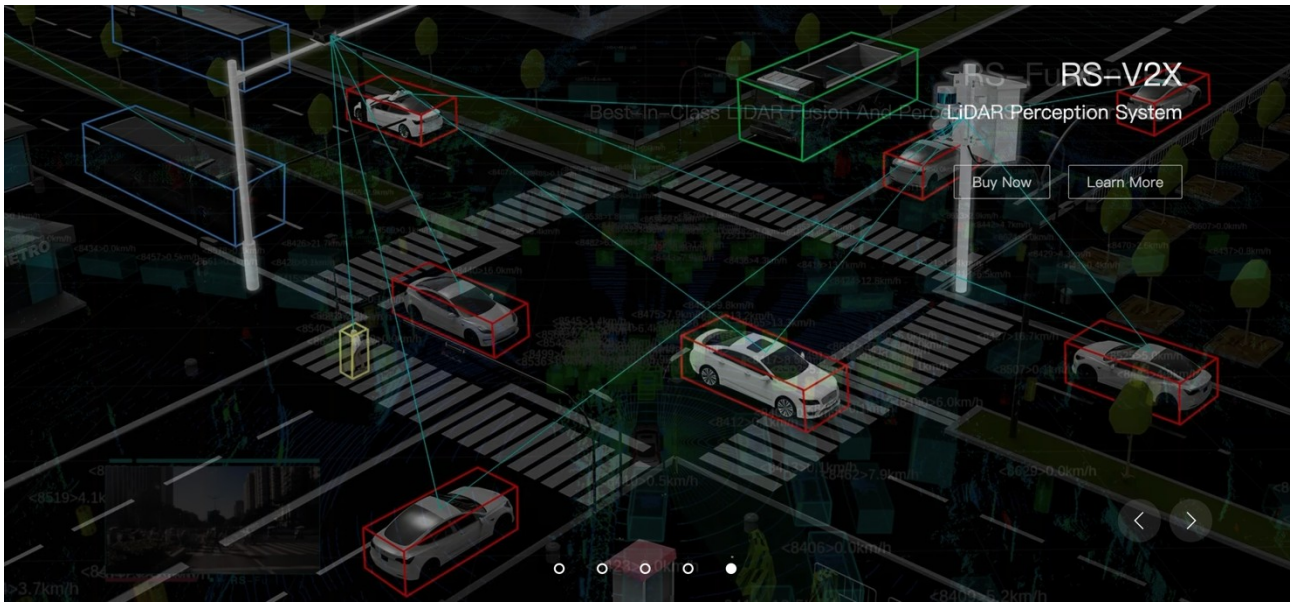


53. Robosense (China), https://www.robosense.ai/en

Source: < https://www.robosense.ai/en>


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ROI resolution 0.2°

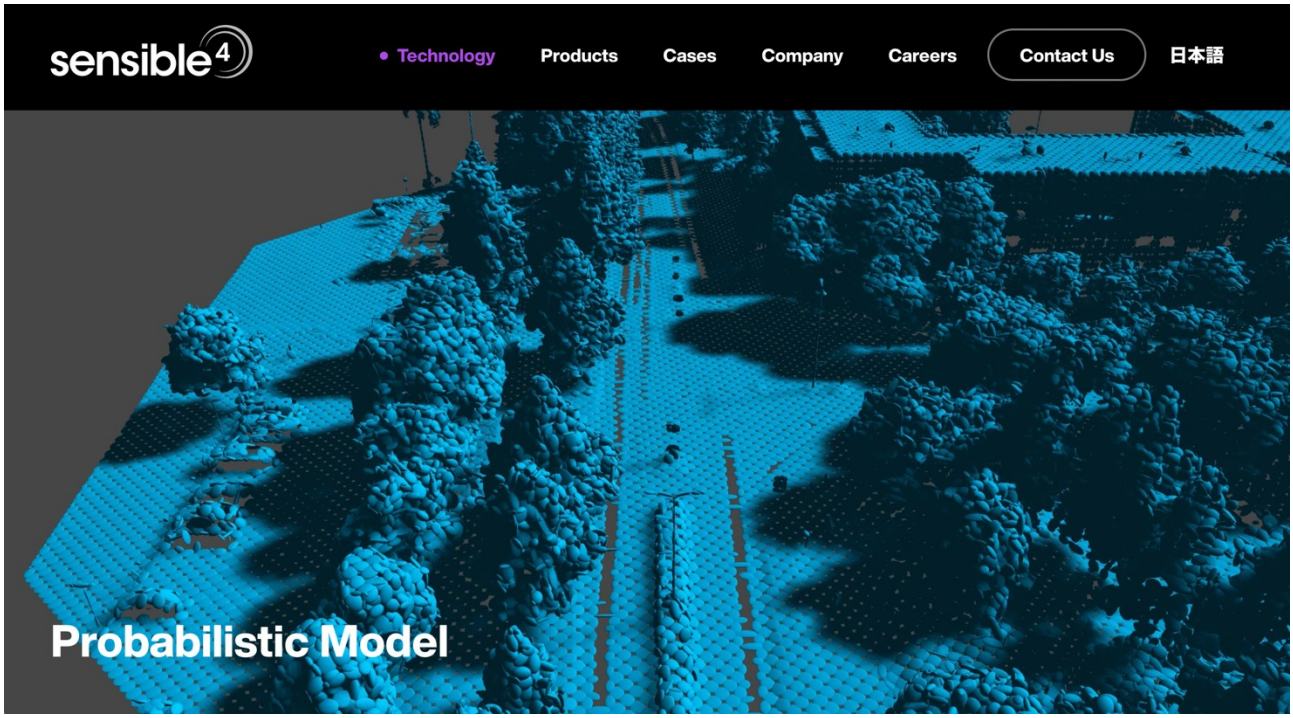

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54. Sense Photonics

No website available.

55. Sensible 4 (Finland), https://sensible4.fi/
Source: https://sensible4.fi/technology/

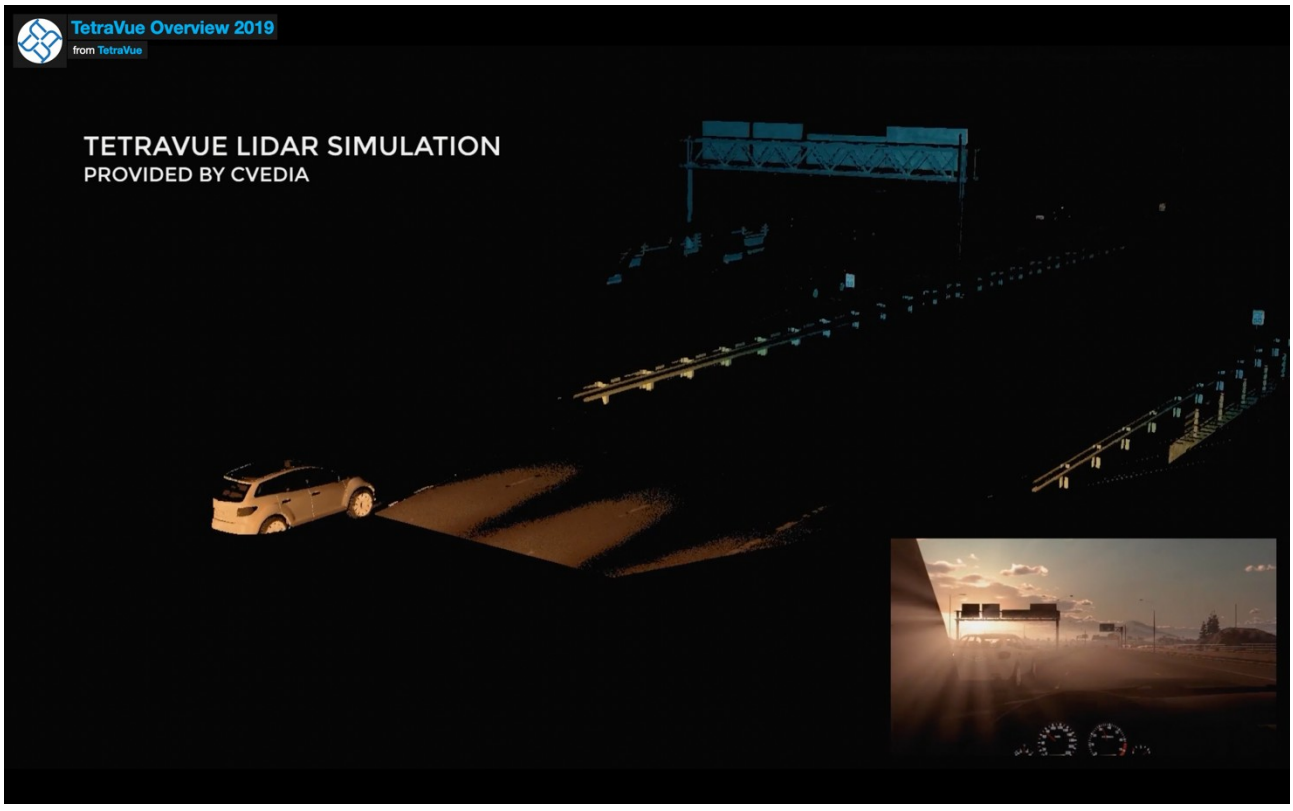


56. Strobe
No website available.

57. TetraVue (USA), https://sensible4.fi/technology/

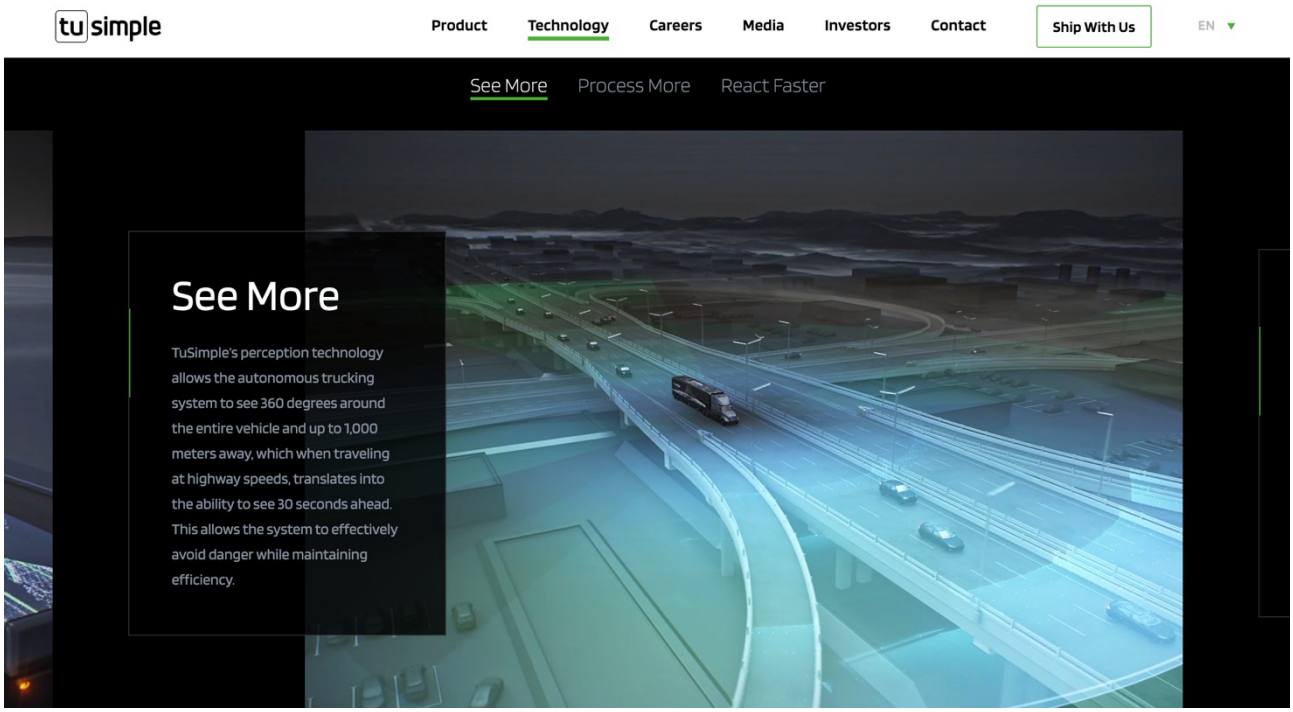
Source: <https://tetravue.webflow.io/>



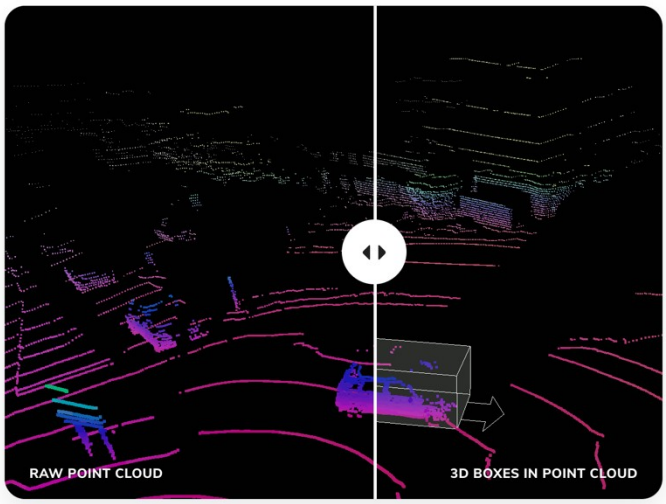


58. Trilumina
No website available.

59. Tusimple (USA), <https://www.tusimple.com/>
Source: < https://www.tusimple.com/technology/>



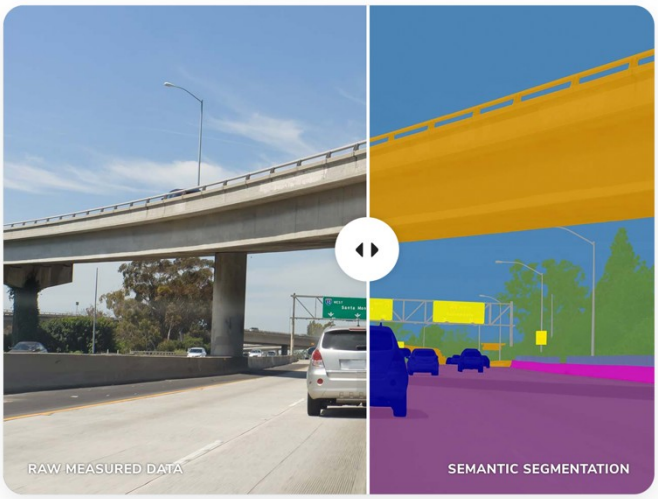
60. Understand.ai (Germany), <https://understand.ai/>
Source: <https://understand.ai/data-annotation-tool.html>



3D LiDAR Bounding Boxes

LiDAR is an active optical sensor technology which scans the earth's surface to determine highly accurate x, y and z measurements. It transmits laser beams to a specific object and reflects its movements back to the receiver and analyzes the time span and distance with GPS and INS information to construct a 3D point cloud of reflective obstacles. LiDAR adds complementary information and is very strong at detecting pedestrians and other non-metallic objects at night, a scenario in which camera and RADAR sensors often fail.

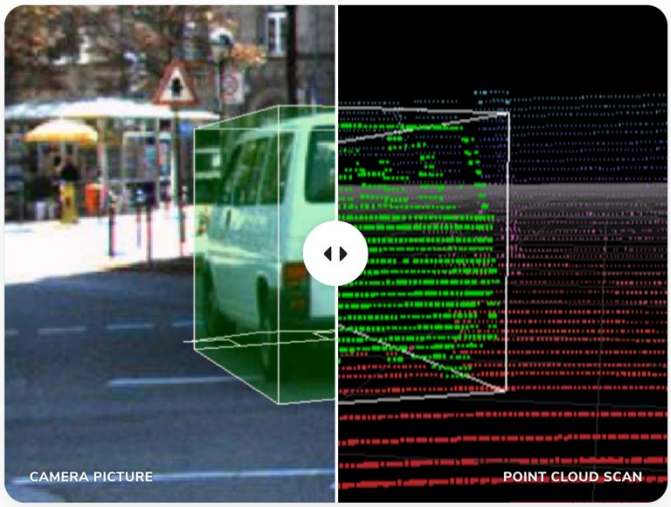
Our **UAI Annotator** covers all your needs of fast, high quality and reliable labeling of 3D bounding boxes or cuboids for LiDAR, through a highly automated tool designed to give your labellers superpowers. Thanks to superior 3D point cloud handling millions of points are processed smoothly, navigated with ease and integrated seamlessly into the workflow.



2D & 3D Semantic Segmentation

Depending on the raw data, bounding boxes can contain noise in the form of background and occlusions. This is tackled with semantic segmentation, where each pixel assigned to the class of your selected objects will be annotated. It is therefore the closest to a true representation of reality in 2D & 3D space, regarding class assignments. It also is more versatile, since it is very easy to distinguish between objects, e.g., road, lanes and curbs and track instances of them throughout the sequence.

UAI is the only tooling provider capable of annotating and exporting 2D segmentations in both pixel-based and polygon-based modes. UAI Annotator removes the complexity of semantic segmentation by automating the tricky bits, reduces the costs associated with the annotation process and its set-up.



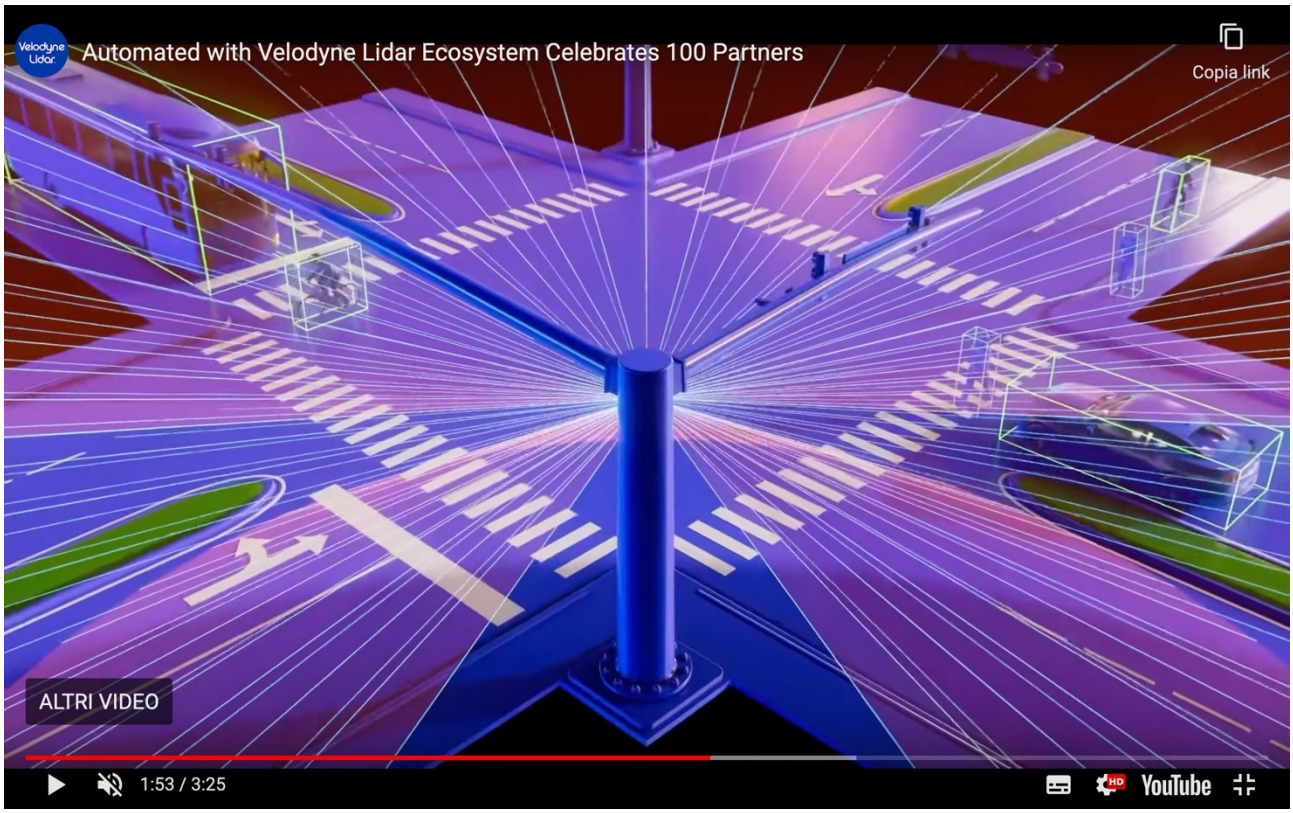
3D Sensor Fusion Annotation

Sensor fusion is commonly defined as the fusion of inputs from multiple sensors, such as radar, lidar and cameras with the goal to create a virtual model of the environment around the vehicle. The combination of different sensor types allows for a much more complete representation of the real world then a single sensor could possibly provide.

Understand.ai is specialized on sensor fusion projects and can provide an unprecedented level of automation in this area.

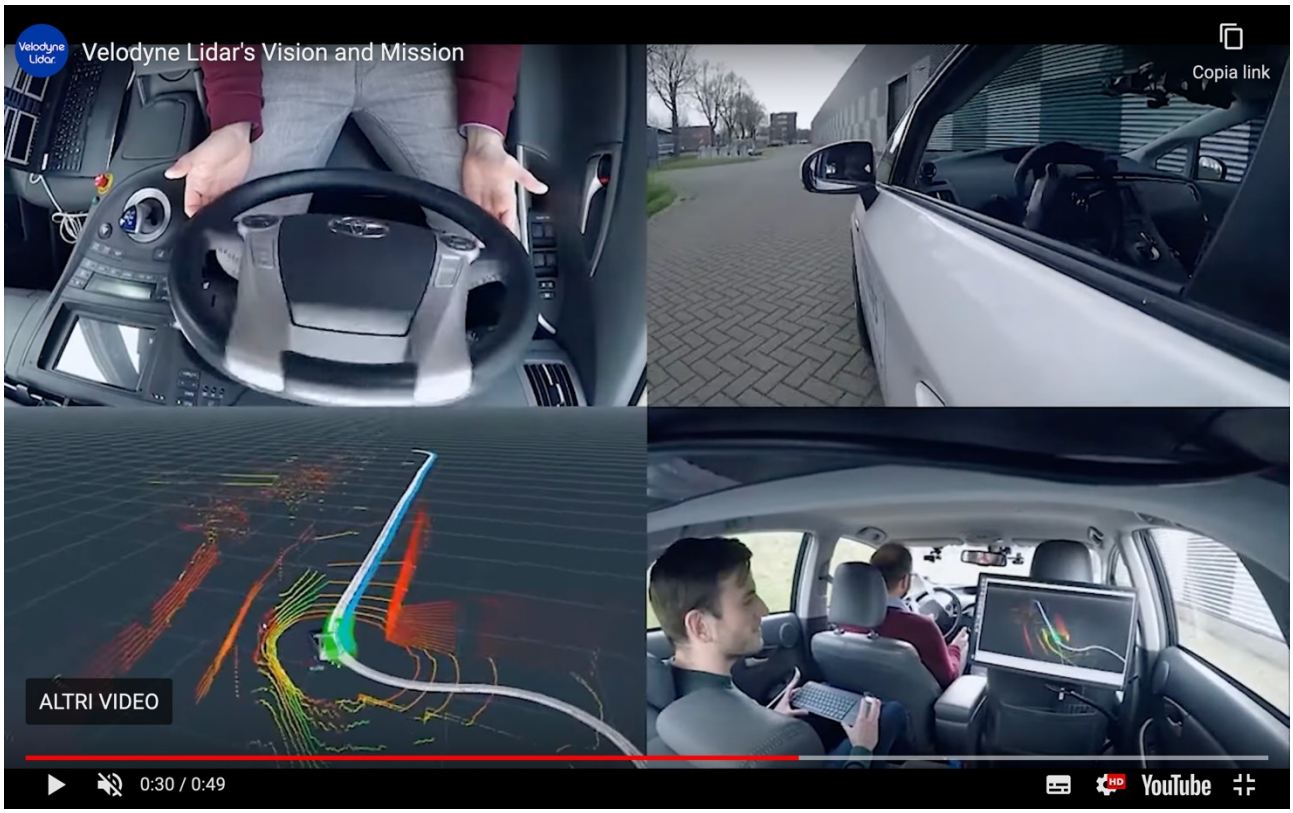
61. Valeo (France)
No website available.

62. Velodyne (USA), https://velodynelidar.com/
Source: https://velodynelidar.com/

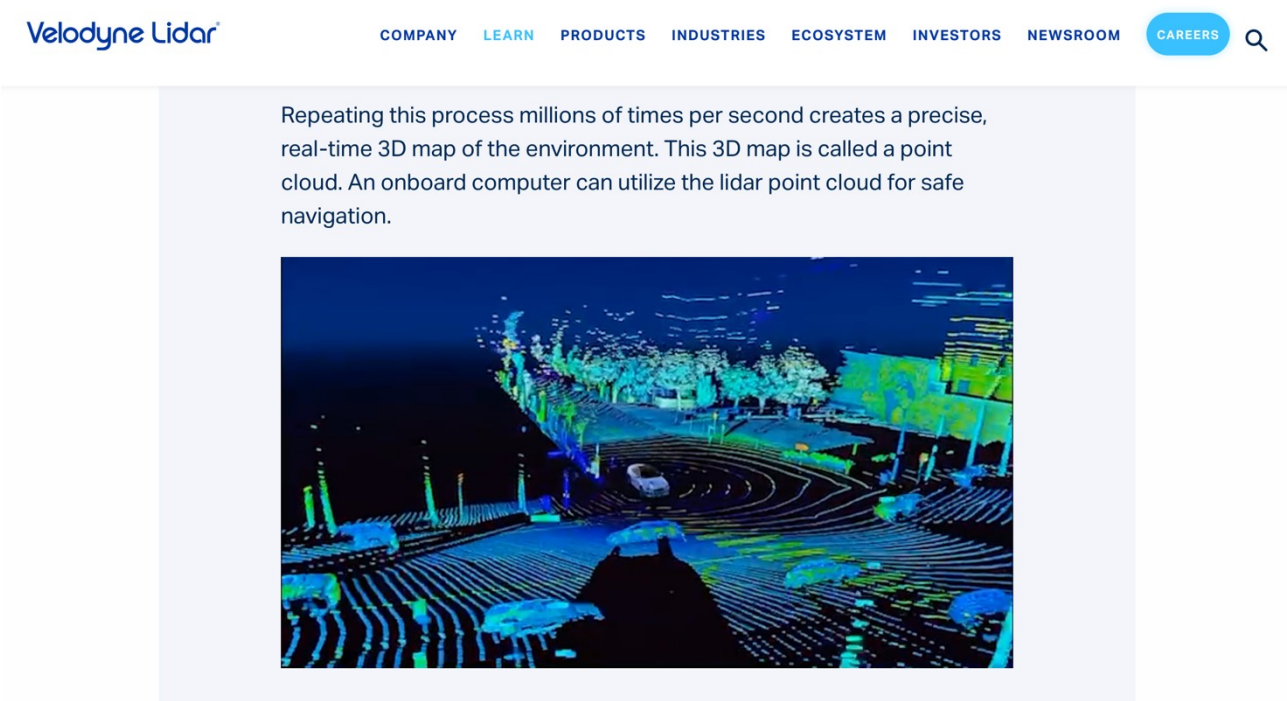

Automated with Velodyne Lidar Ecosystem Celebrates 100 Partners
Copia link
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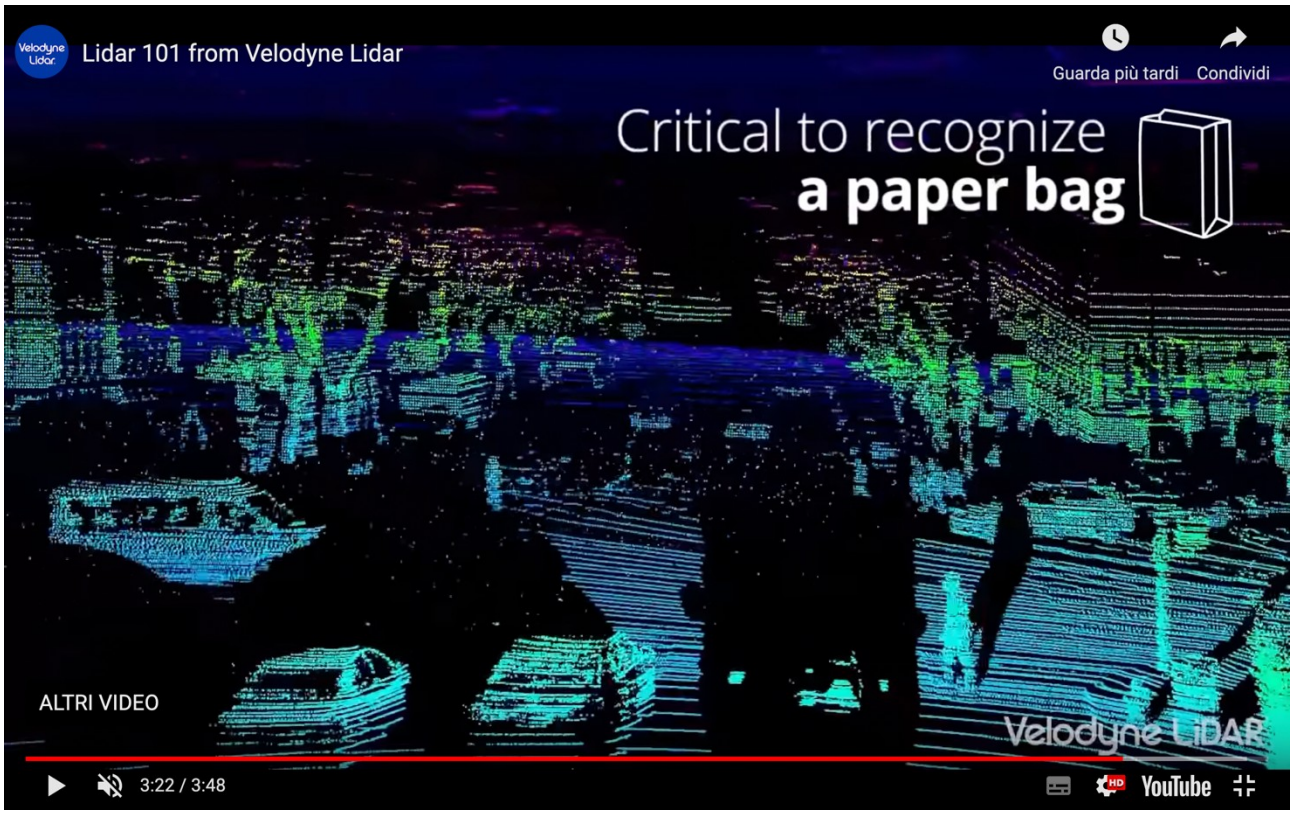

Automated with Velodyne Lidar Ecosystem Celebrates 100 Partners
Copia link
Velodyne Lidar
Intelligent Infrastructure Solution
Powered By Bluecity
ALTRI VIDEO
1:57 / 3:25
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Source: < https://velodynelidar.com/what-is-lidar/>



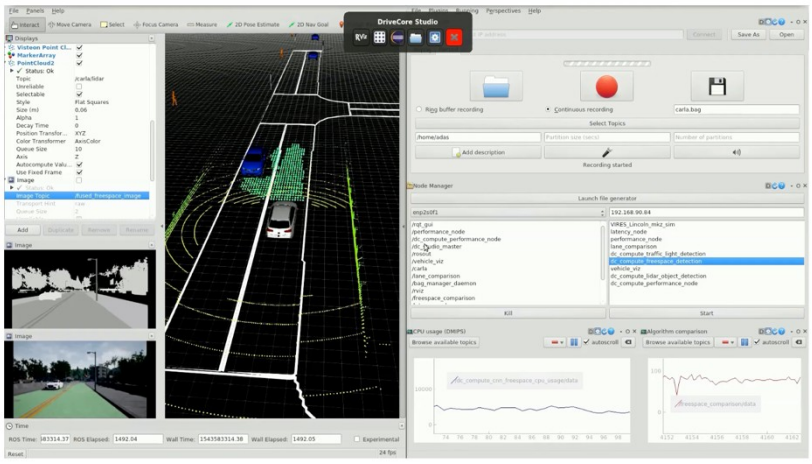


63. Vislab (Italy)
No images available.

64. Visteon Corporation (USA), < https://www.visteon.com/>
Source: https://www.visteon.com/products/autonomous/

Driving collaboration with DriveCore™ Studio

The future of autonomous driving is something that can't be tackled without collaboration. DriveCore™ Studio, Visteon's powerful PC and cloud-based tool for algorithm development, allows software developers to manage DriveCore™ Runtime environments and 3D simulations, so they can explore real-world or synthetic autonomous driving data. Record data from the bench or vehicle, then visualize, profile and analyze software behavior. By using DriveCore™ Studio, you can share data via cloud service and collaborate to create the next generation of mobility.



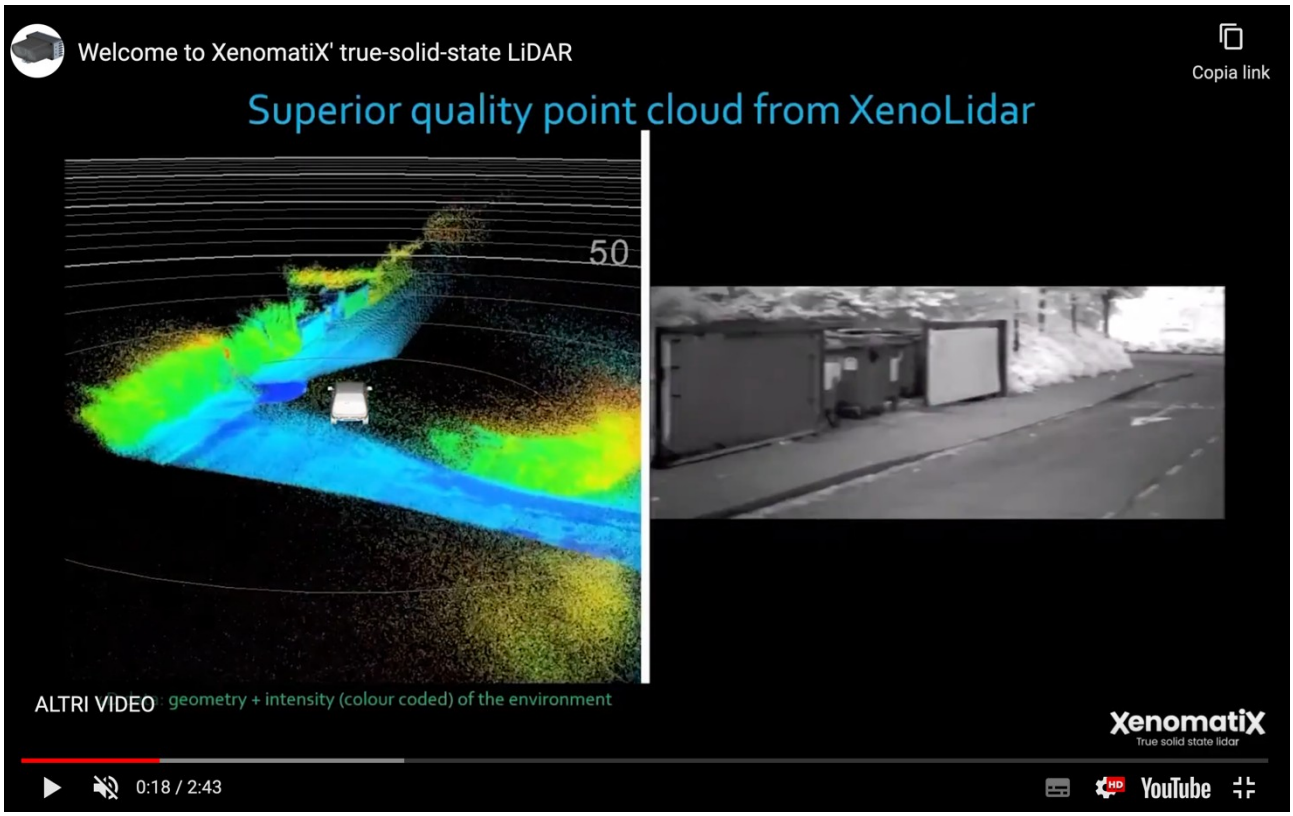
65. Waymo (USA), < https://waymo.com/>

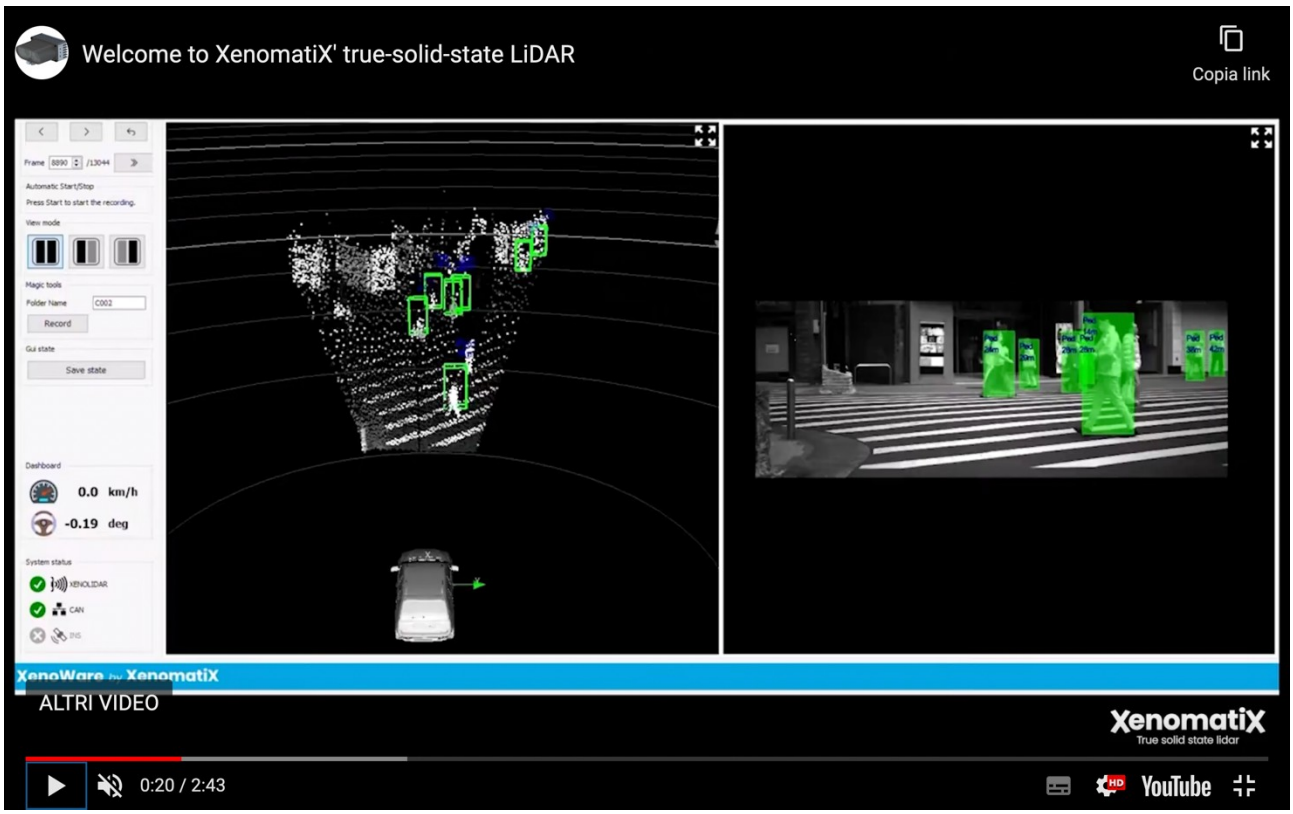
Source: < https://waymo.com/waymo-driver/>



67. Xenomatix (Belgium), https://xenomatix.com/

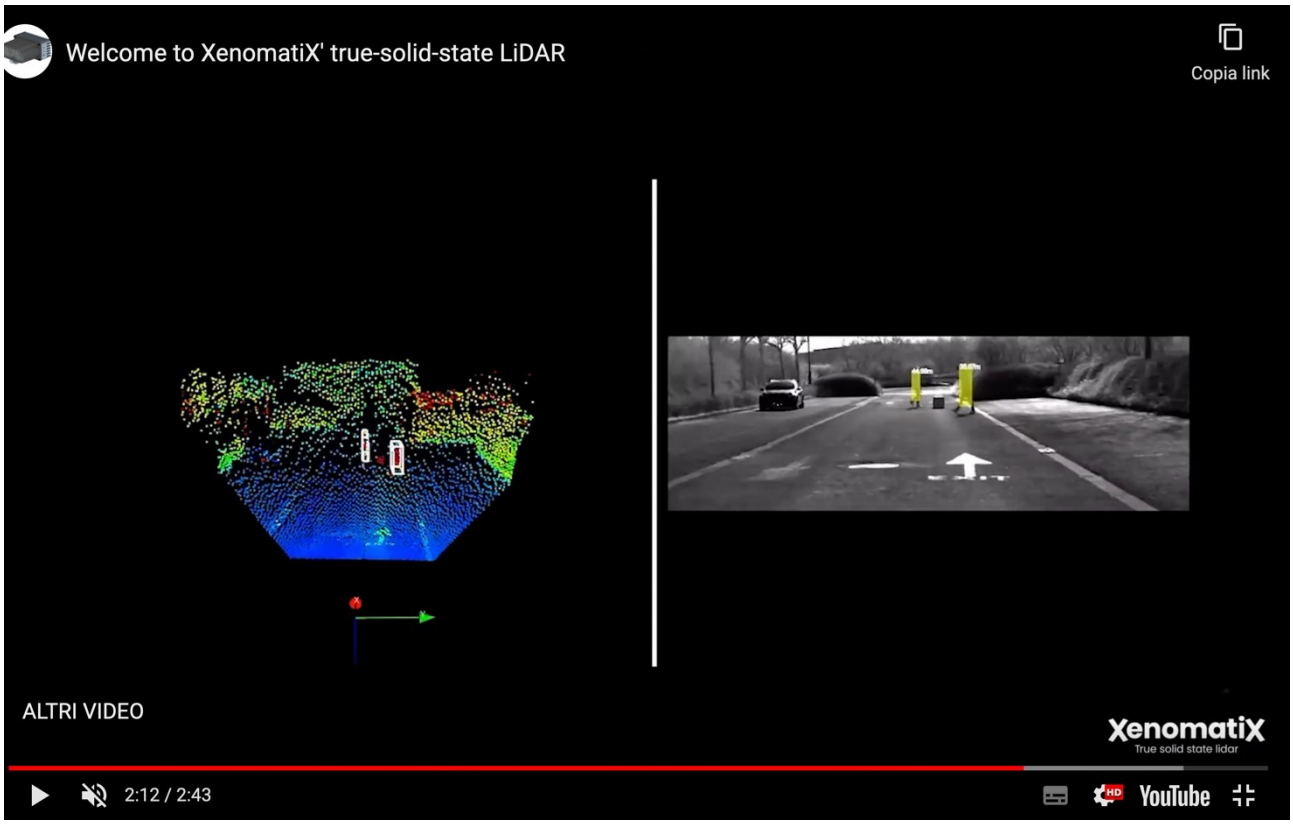
Source: < https://xenomatix.com/>


Welcome to XenomatiX' true-solid-state LiDAR
Copia link
Superior quality point cloud from XenoLidar
50
ALTRI VIDEO
geometry + intensity (colour coded) of the environment
XenomatiX
True solid state lidar
0:18 / 2:43
YouTube


Welcome to XenomatiX' true-solid-state LiDAR
Copia link
Automatic Start/Stop
Press Start to start the recording.
View mode
Magic tools
Folder Name
C002
Record
Gui state
Save state
Dashboard
0.0 km/h
-0.19 deg
System status
XENOLIDAR
CAN
XenoWare by XenomatiX
ALTRI VIDEO
XenomatiX
True solid state lidar
0:20 / 2:43
YouTube

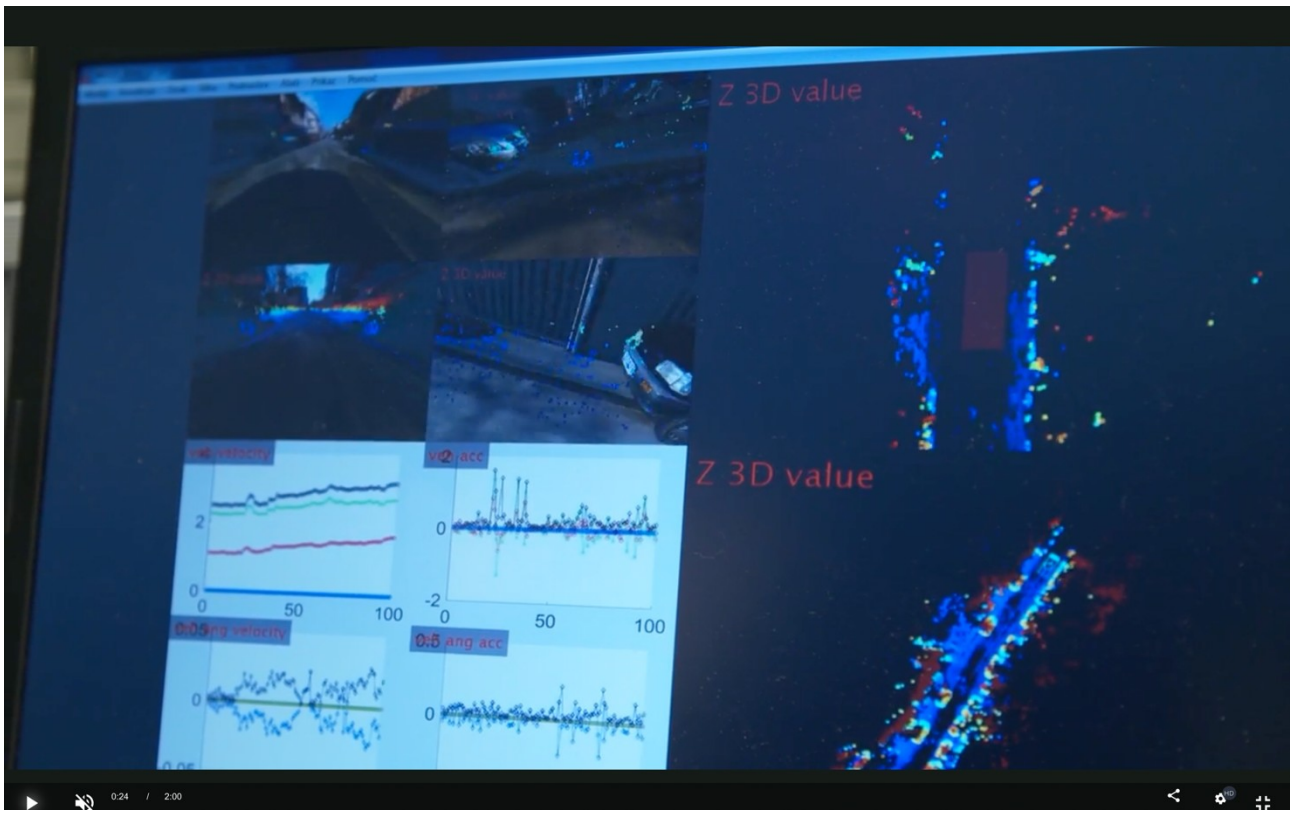

Welcome to XenomatiX' true-solid-state LiDAR
Copia link
ALTRI VIDEO
XenomatiX
True solid state lidar
0:26 / 2:43
YouTube

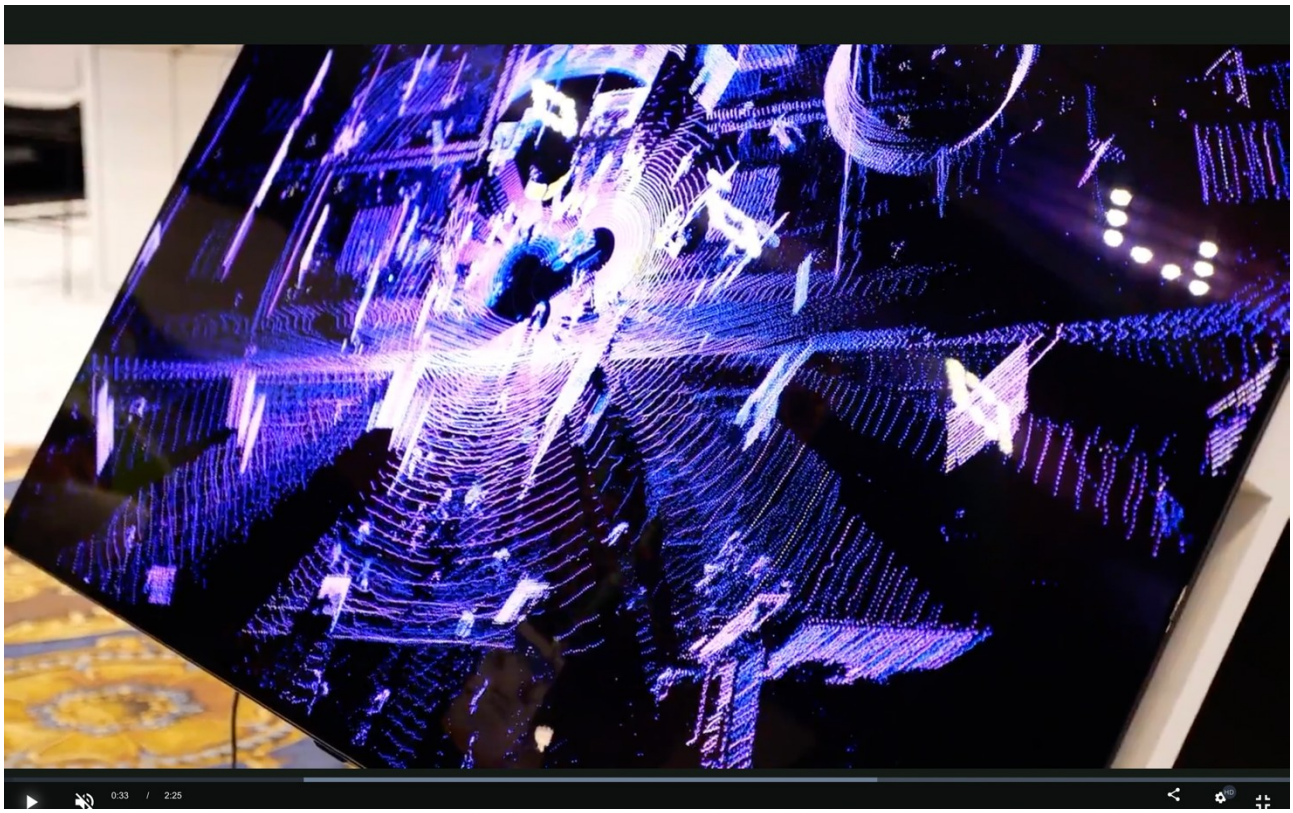

Welcome to XenomatiX' true-solid-state LiDAR
Copia link
Identify all road distress
ALTRI VIDEO
XenomatiX
True solid state lidar
1:10 / 2:43
YouTube



68. Xilinx (USA), https://www.xilinx.com/

Source: <https://www.xilinx.com/applications/automotive/adas.html>





69. Yandex (Russia)

No images available.

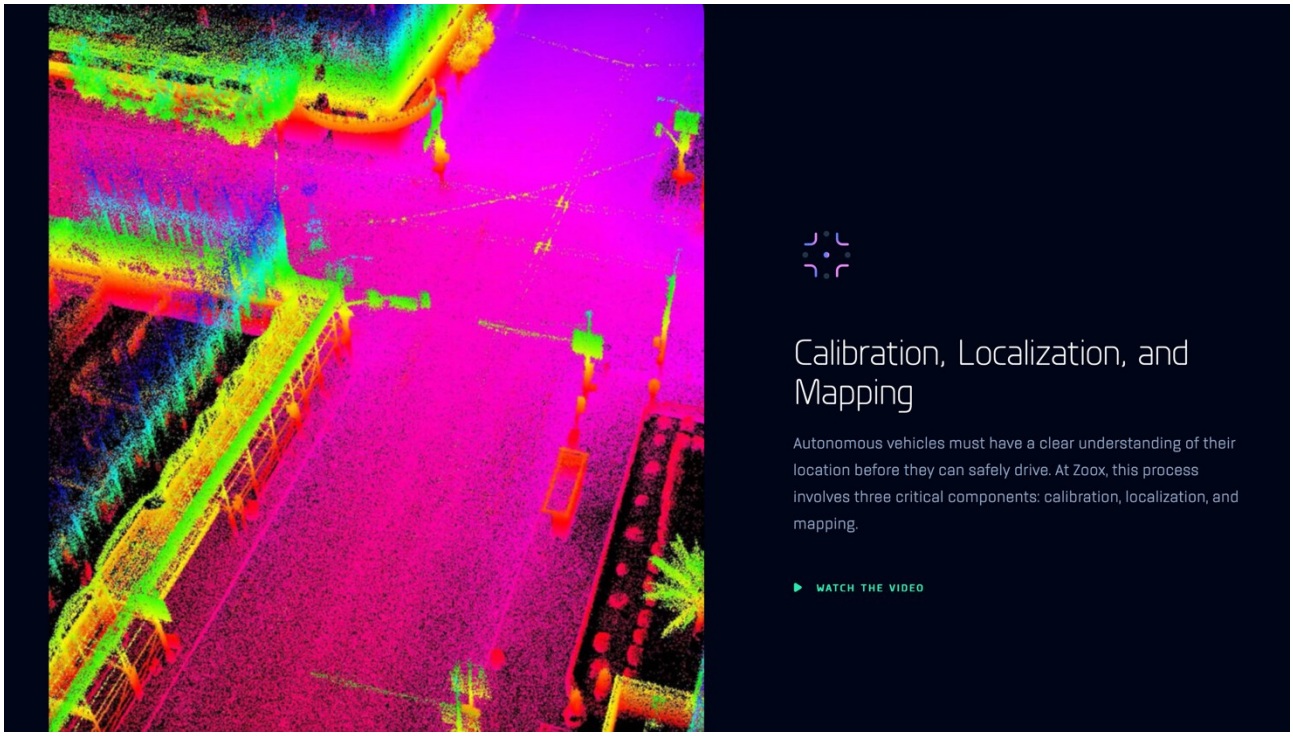
70. Zoox (USA), https://zoox.com/

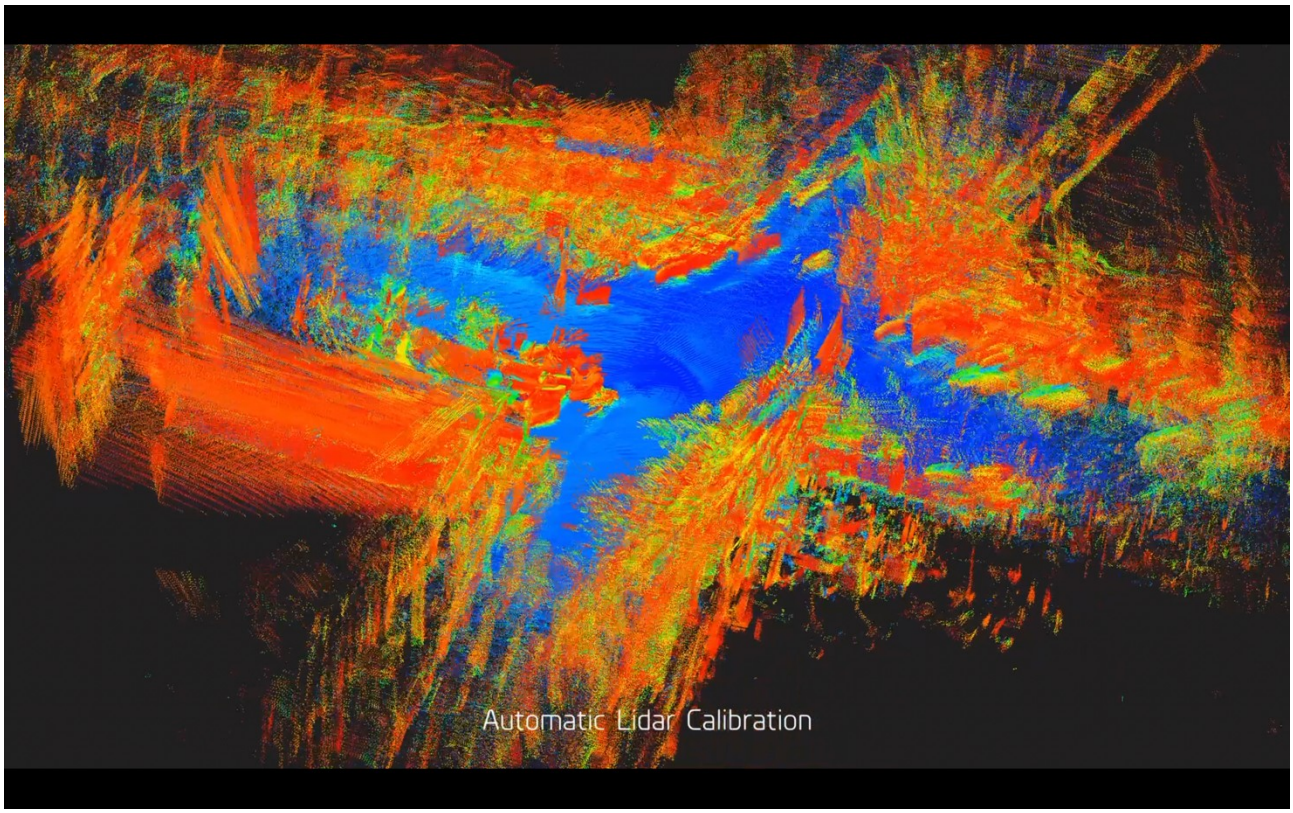
Source: https://zoox.com/autonomy/

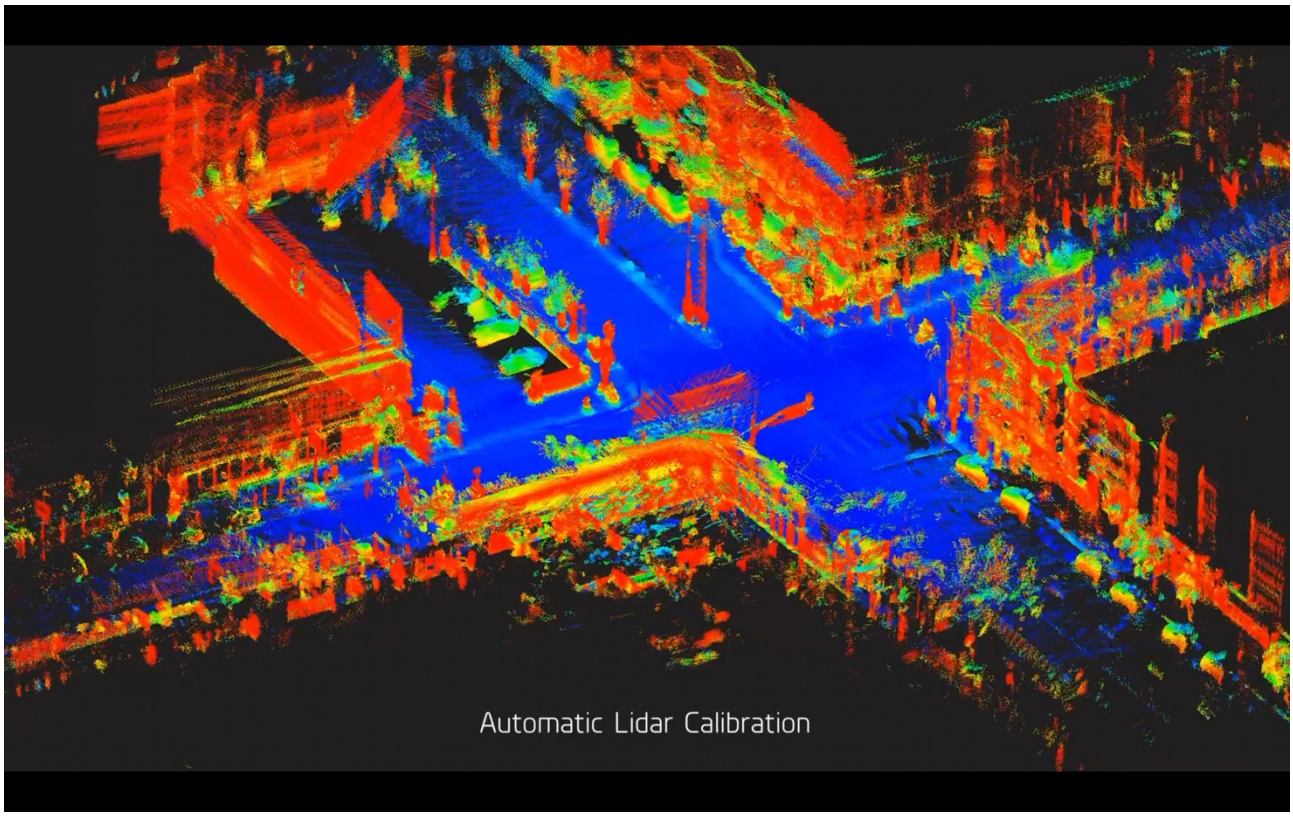

A
2X SPEED
PARK MGM
FULLY AUTONOMOUS DRIVING

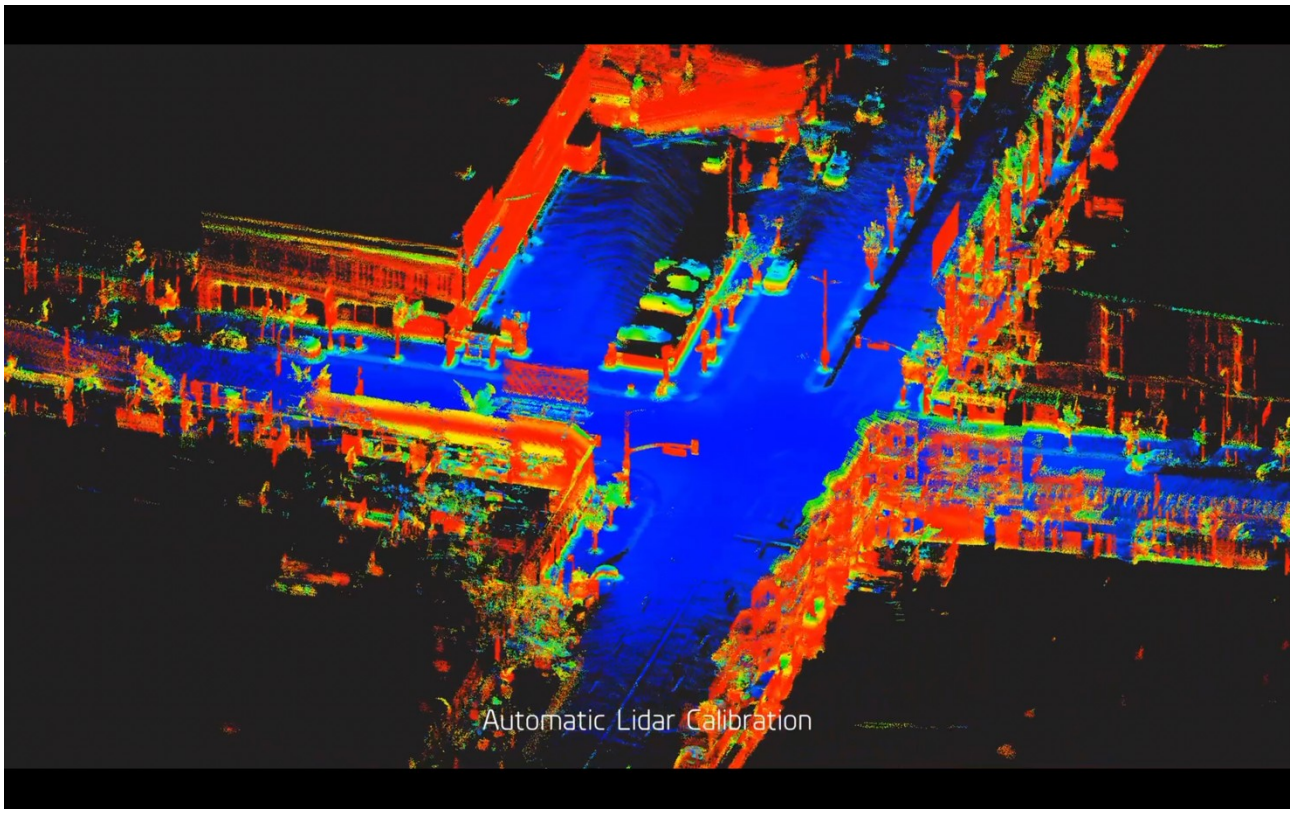

A
2X SPEED
FULLY AUTONOMOUS DRIVING

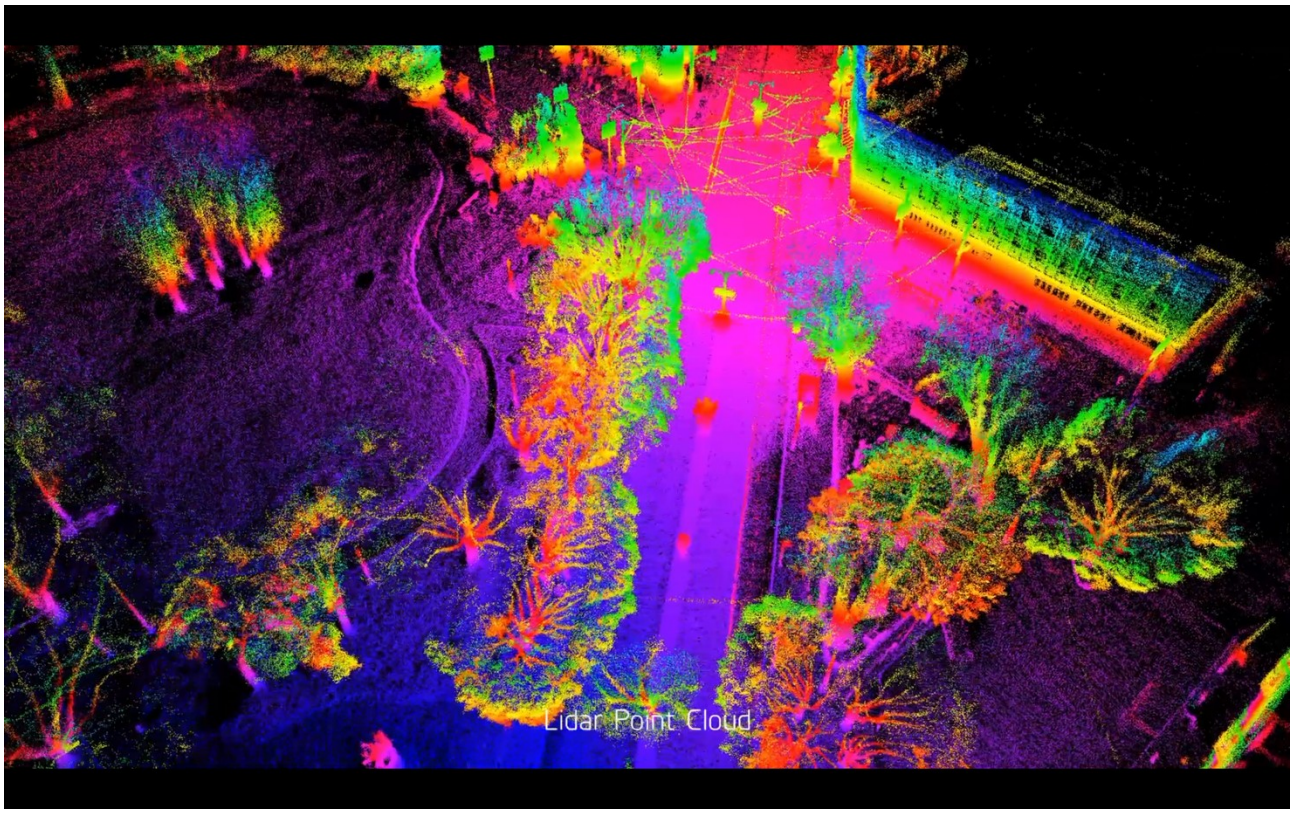

A
2X SPEED
FULLY AUTONOMOUS DRIVING

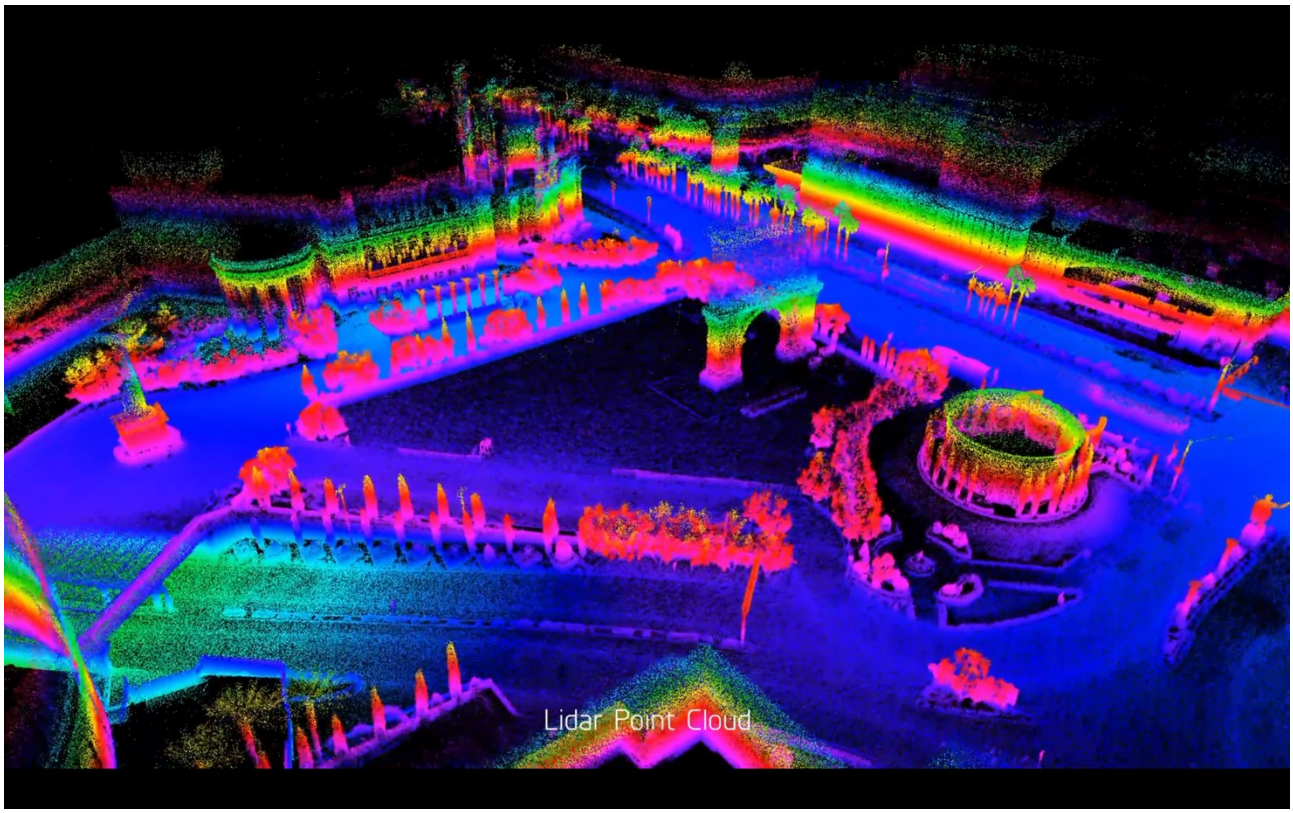

Calibration, Localization, and Mapping
Autonomous vehicles must have a clear understanding of their location before they can safely drive. At Zoox, this process involves three critical components: calibration, localization, and mapping.
WATCH THE VIDEO

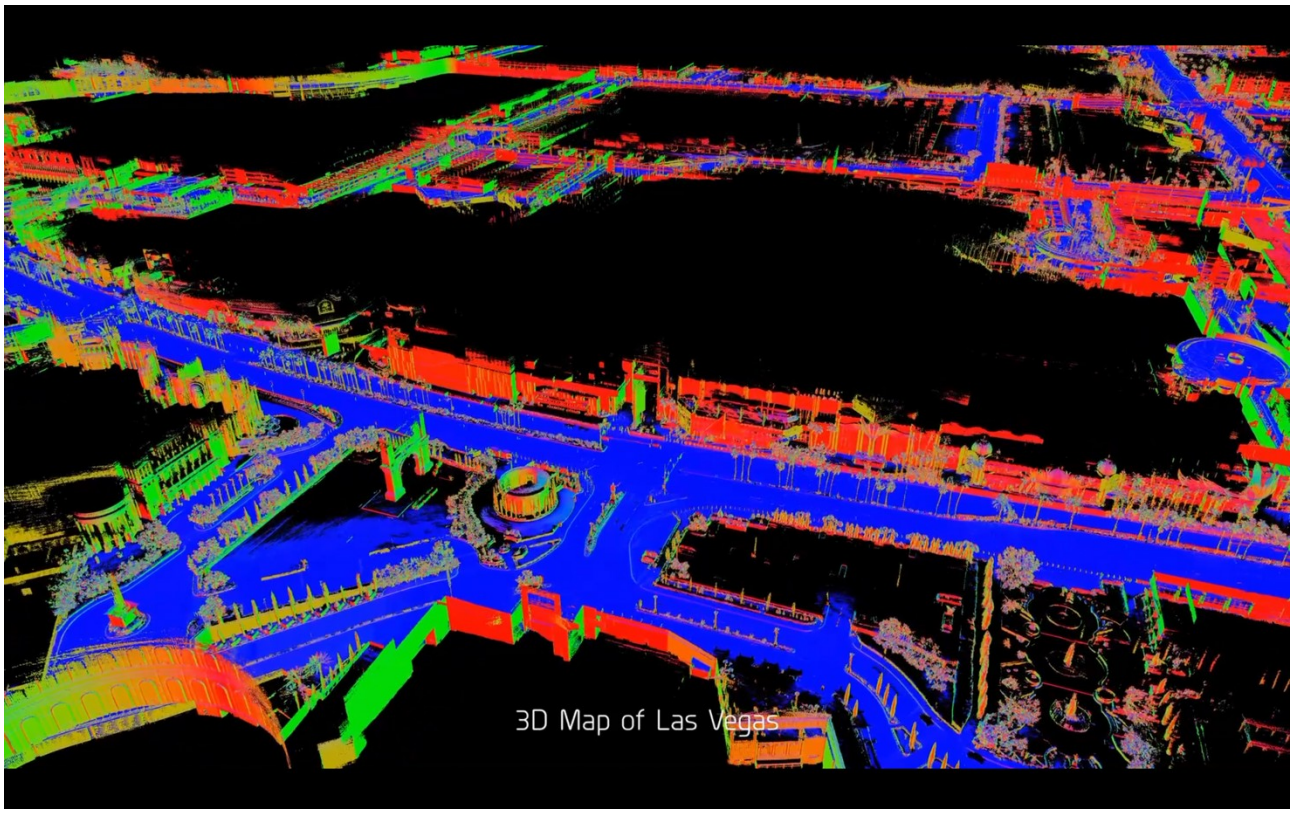

Automatic Lidar Calibration

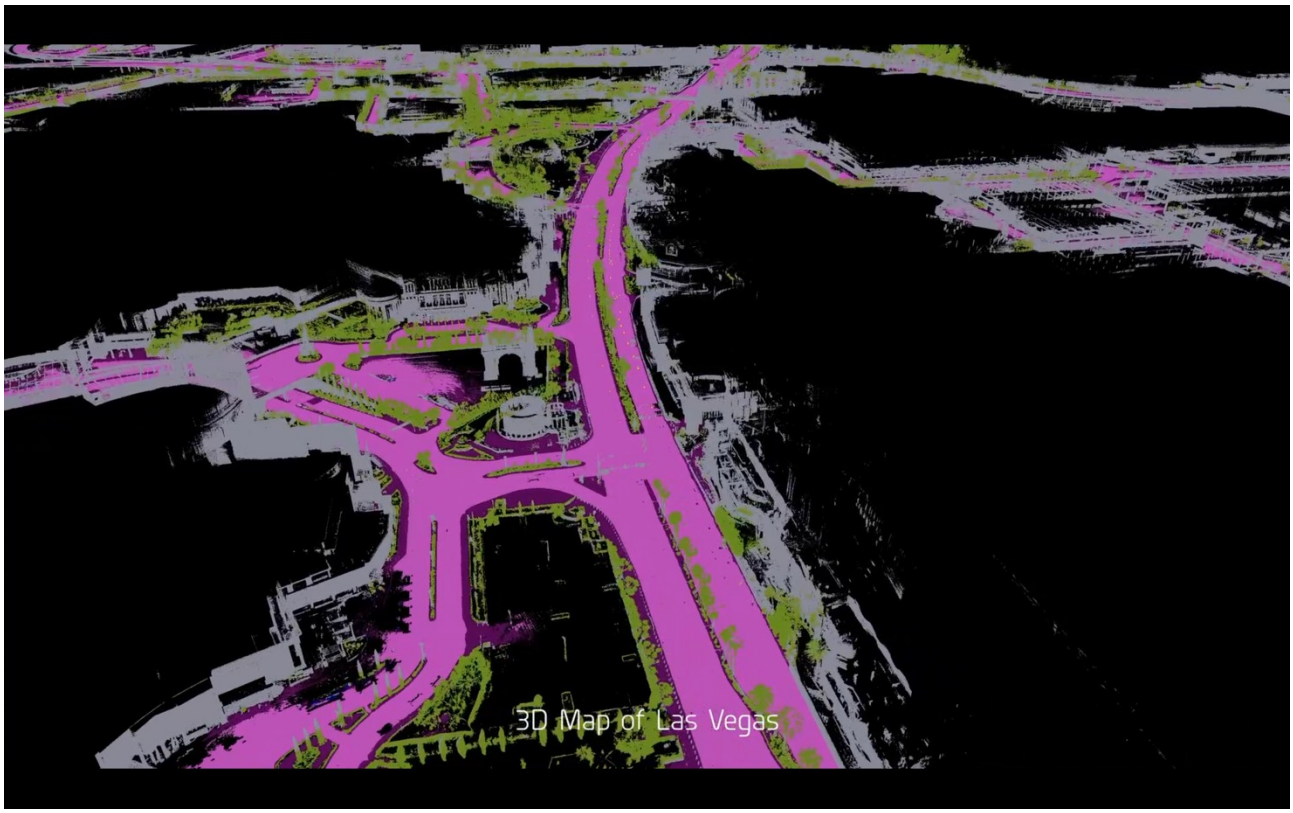

Automatic Lidar Calibration


Automatic Lidar Calibration

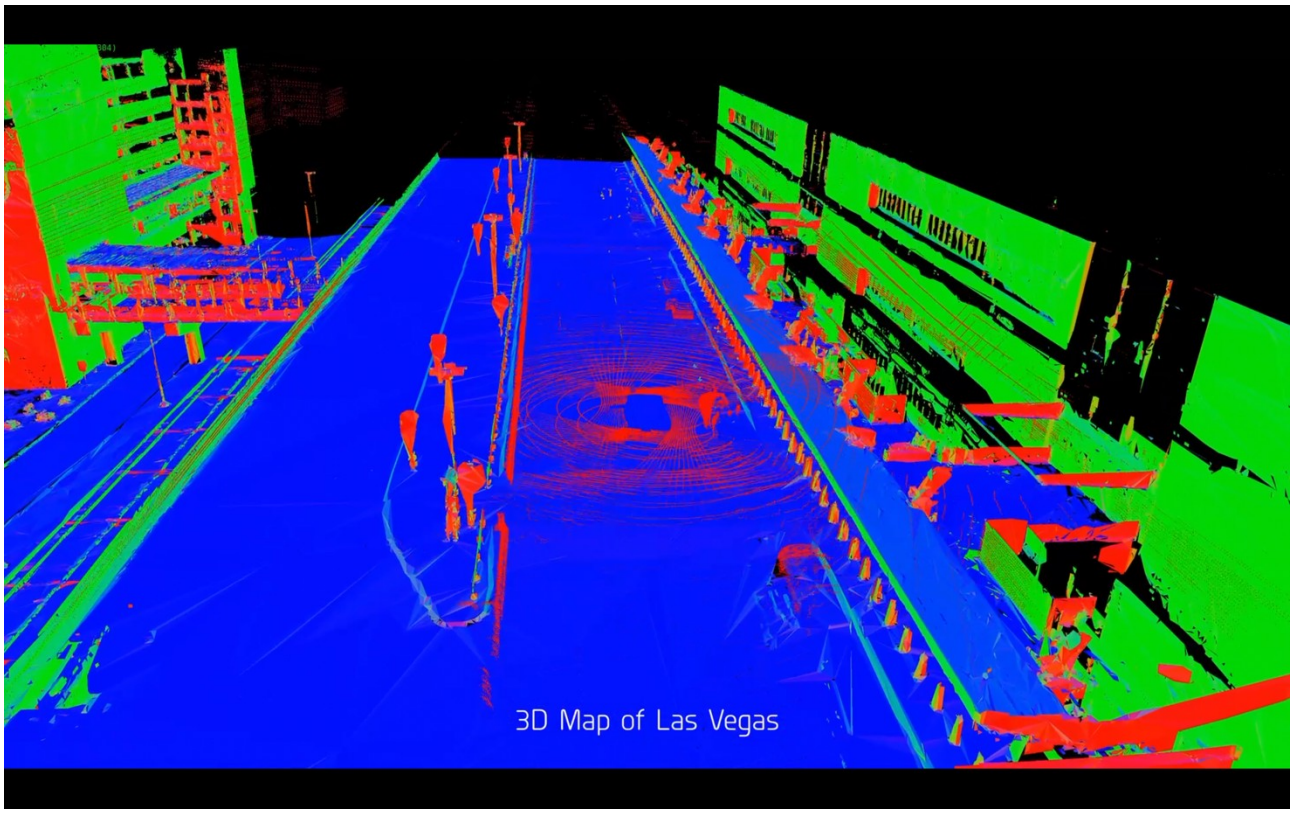

Lidar Point Cloud


Lidar Point Cloud


3D Map of Las Vegas


3D Map of Las Vegas


COMPUTE
KVM
E-STOP
CHARGE ONLY
CAN



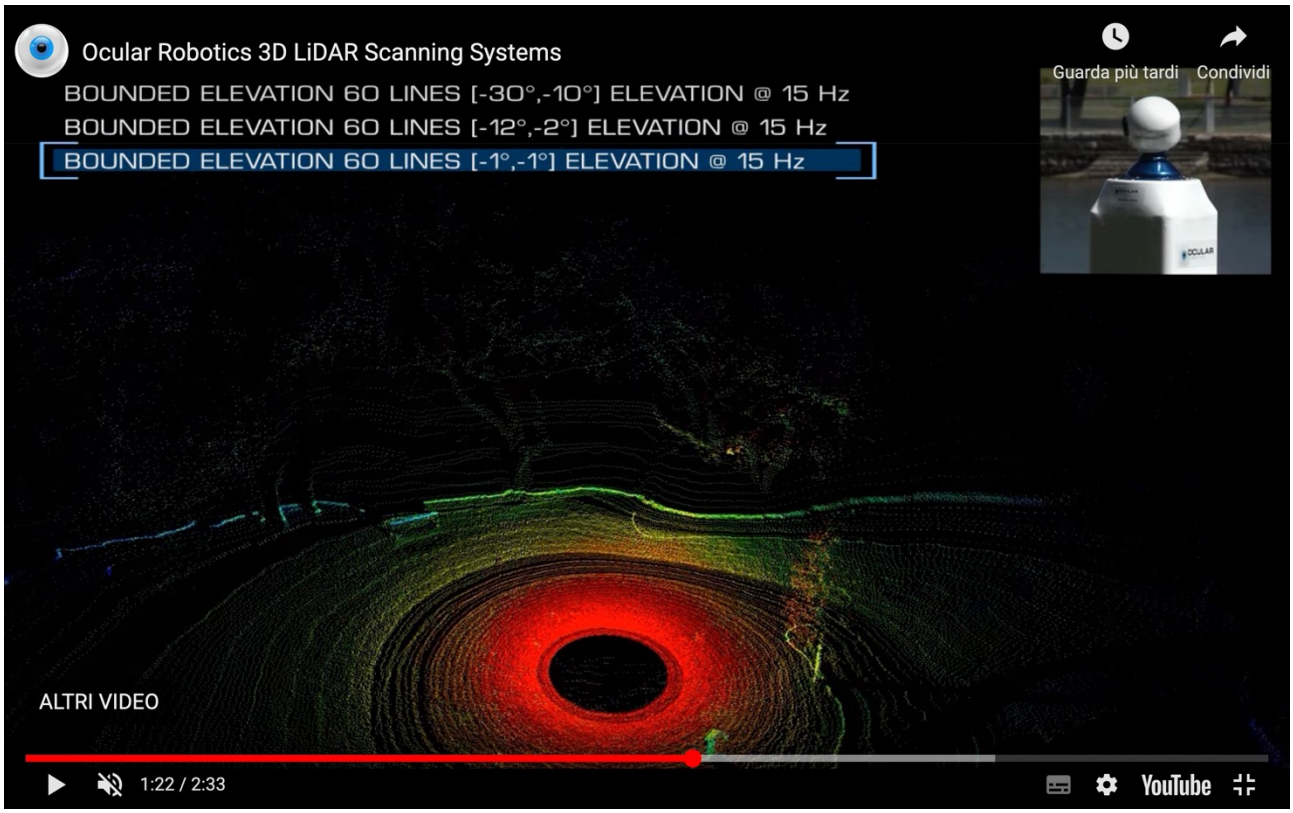
71. Ydlidar (China), https://www.ydlidar.com/

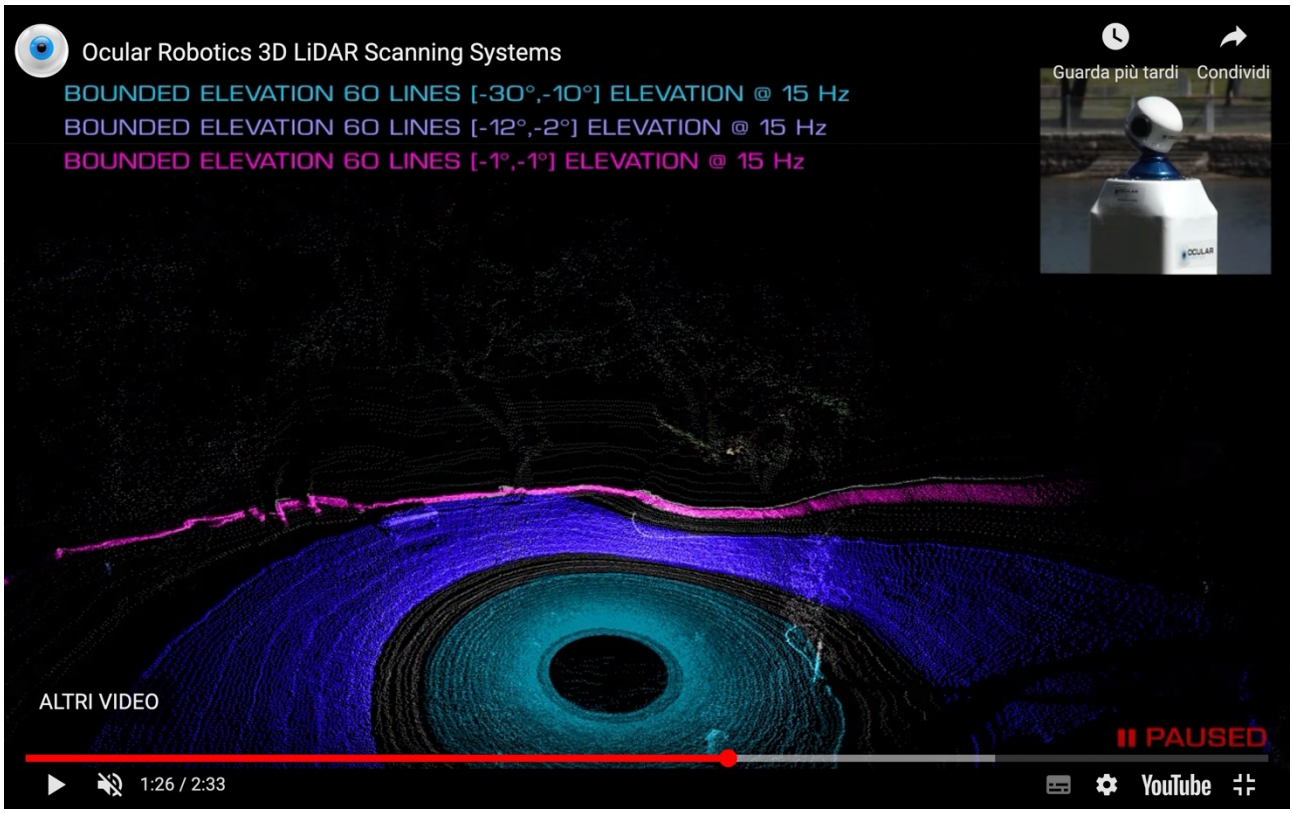
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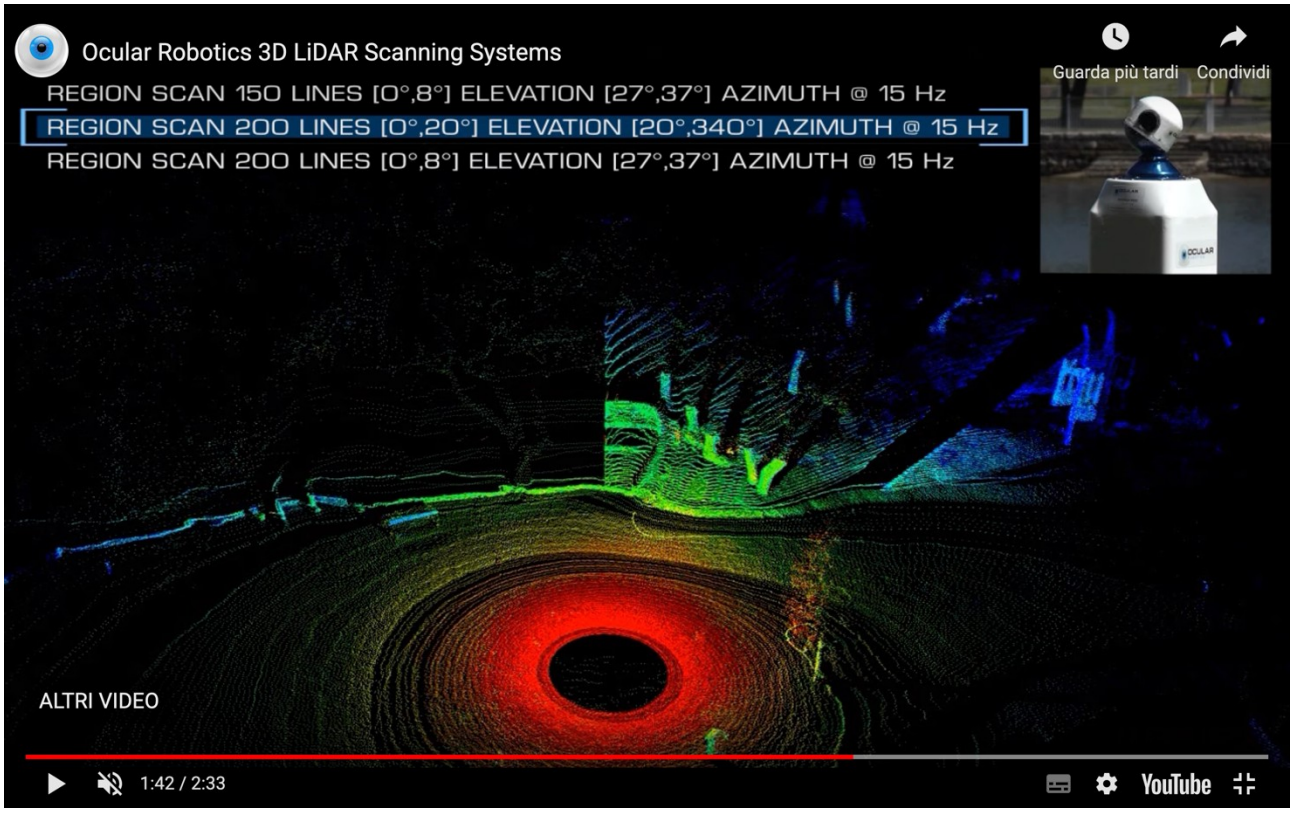
72. Ocular Robotics (Australia), https://www.ocularrobotics.com/

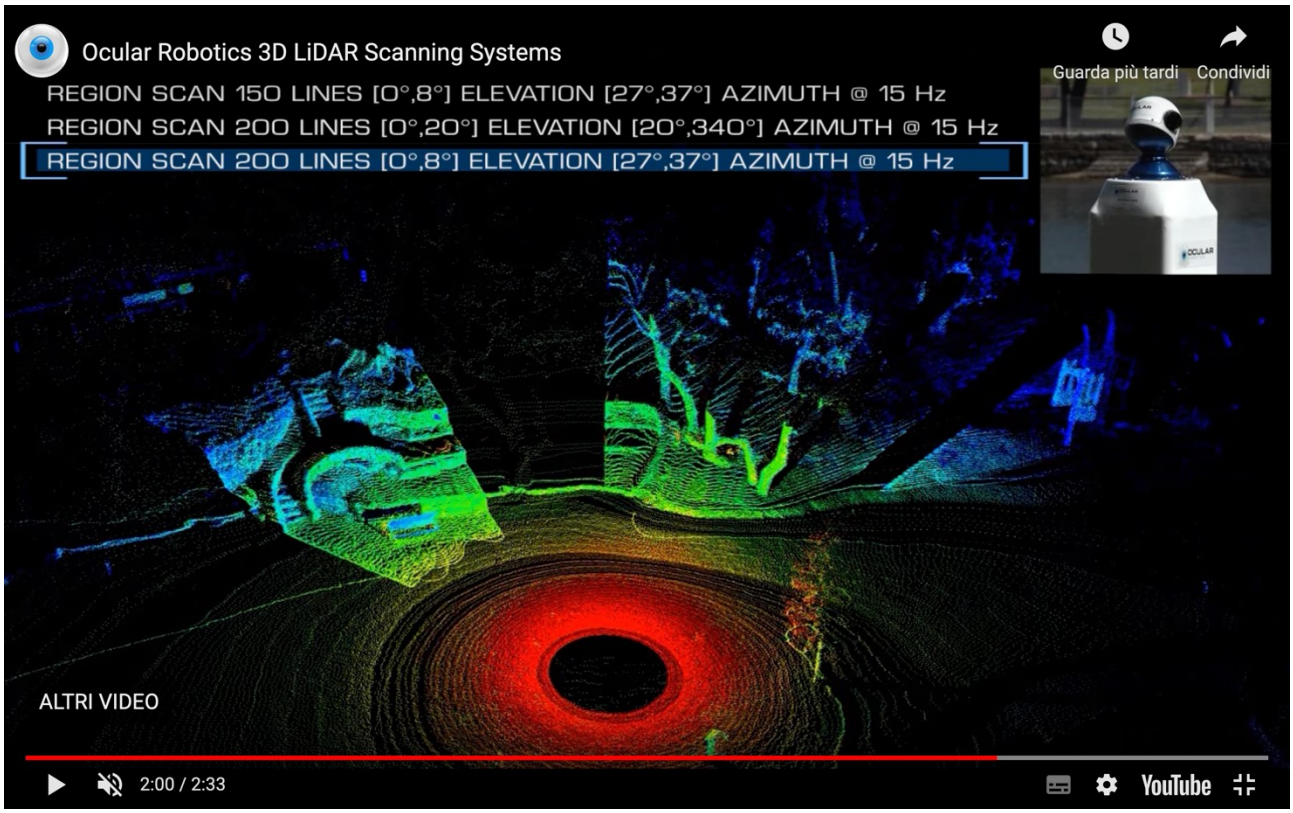
Source: <https://www.ocularrobotics.com/products/lidar/>

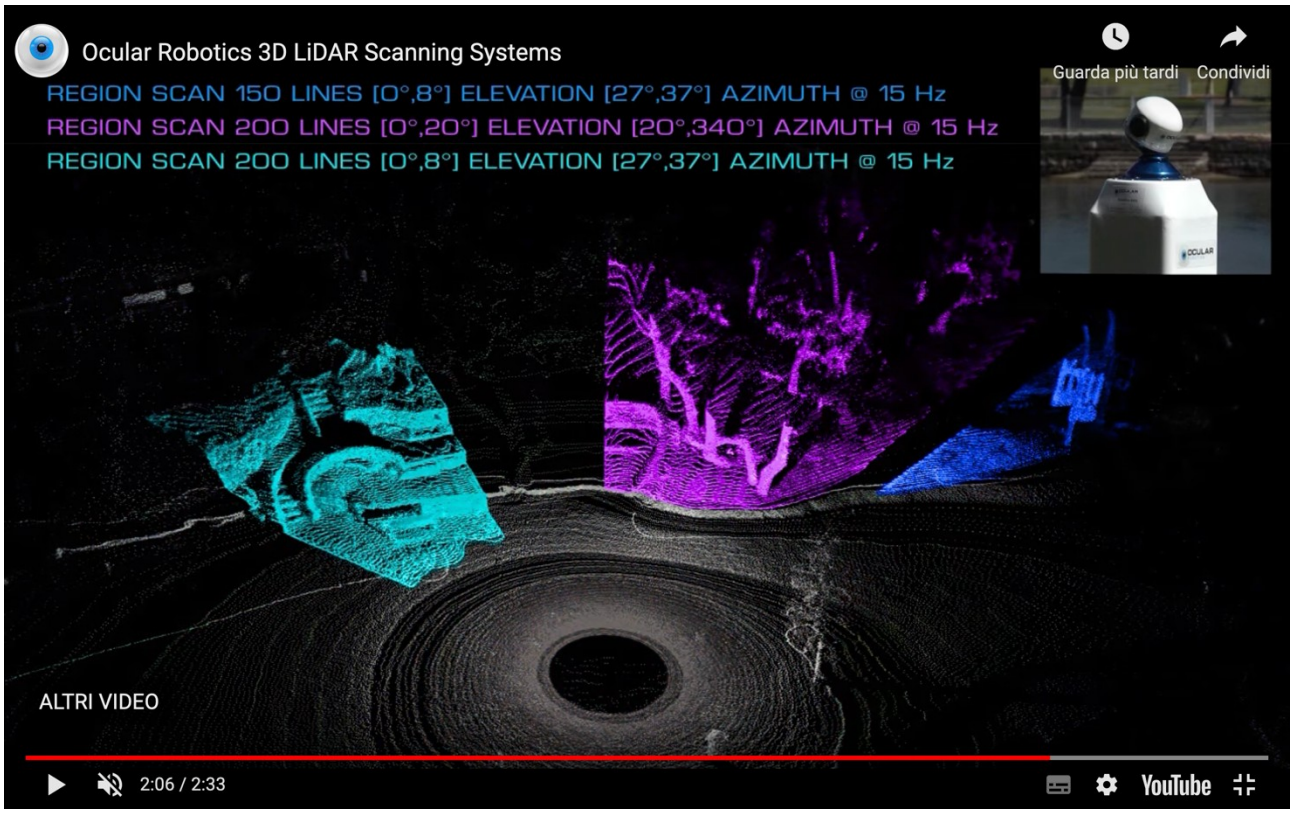

Ocular Robotics 3D LiDAR Scanning Systems
FULL FIELD 300 LINES @ 15 Hz
Guarda più tardi
Condividi
ALTRI VIDEO
PAUSED
0:53 / 2:33
YouTube


Ocular Robotics 3D LiDAR Scanning Systems
BOUNDED ELEVATION 60 LINES [-30°,-10°] ELEVATION @ 15 Hz
BOUNDED ELEVATION 60 LINES [-12°,-2°] ELEVATION @ 15 Hz
BOUNDED ELEVATION 60 LINES [-1°,-1°] ELEVATION @ 15 Hz
Guarda più tardi
Condividi
ALTRI VIDEO
1:22 / 2:33
YouTube


Ocular Robotics 3D LiDAR Scanning Systems
BOUNDED ELEVATION 60 LINES [-30°,-10°] ELEVATION @ 15 Hz
BOUNDED ELEVATION 60 LINES [-12°,-2°] ELEVATION @ 15 Hz
BOUNDED ELEVATION 60 LINES [-1°,-1°] ELEVATION @ 15 Hz
Guarda più tardi
Condividi
ALTRI VIDEO
PAUSED
1:26 / 2:33
YouTube

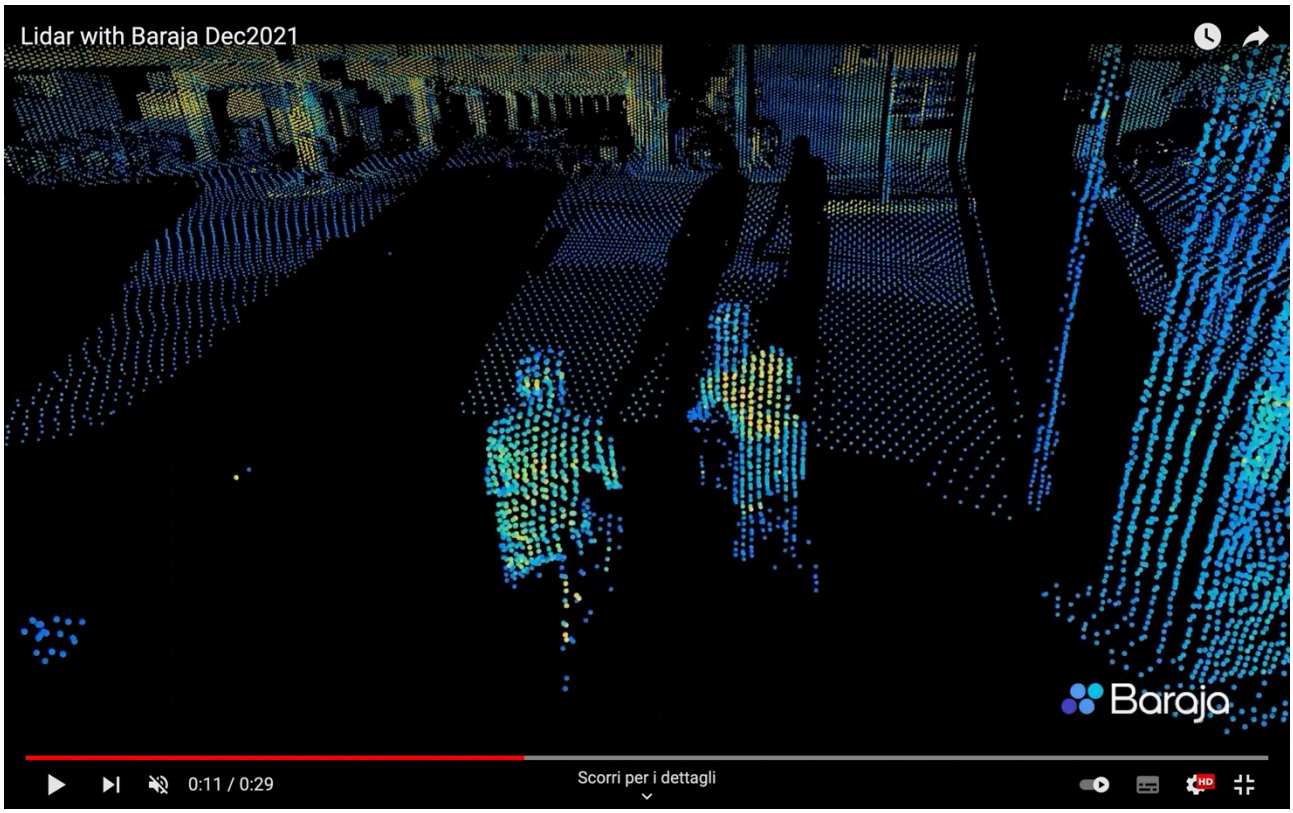

Ocular Robotics 3D LiDAR Scanning Systems
REGION SCAN 150 LINES [0°,8°] ELEVATION [27°,37°] AZIMUTH @ 15 Hz
REGION SCAN 200 LINES [0°,20°] ELEVATION [20°,340°] AZIMUTH @ 15 Hz
REGION SCAN 200 LINES [0°,8°] ELEVATION [27°,37°] AZIMUTH @ 15 Hz
Guarda più tardi
Condividi
ALTRI VIDEO
1:42 / 2:33
YouTube

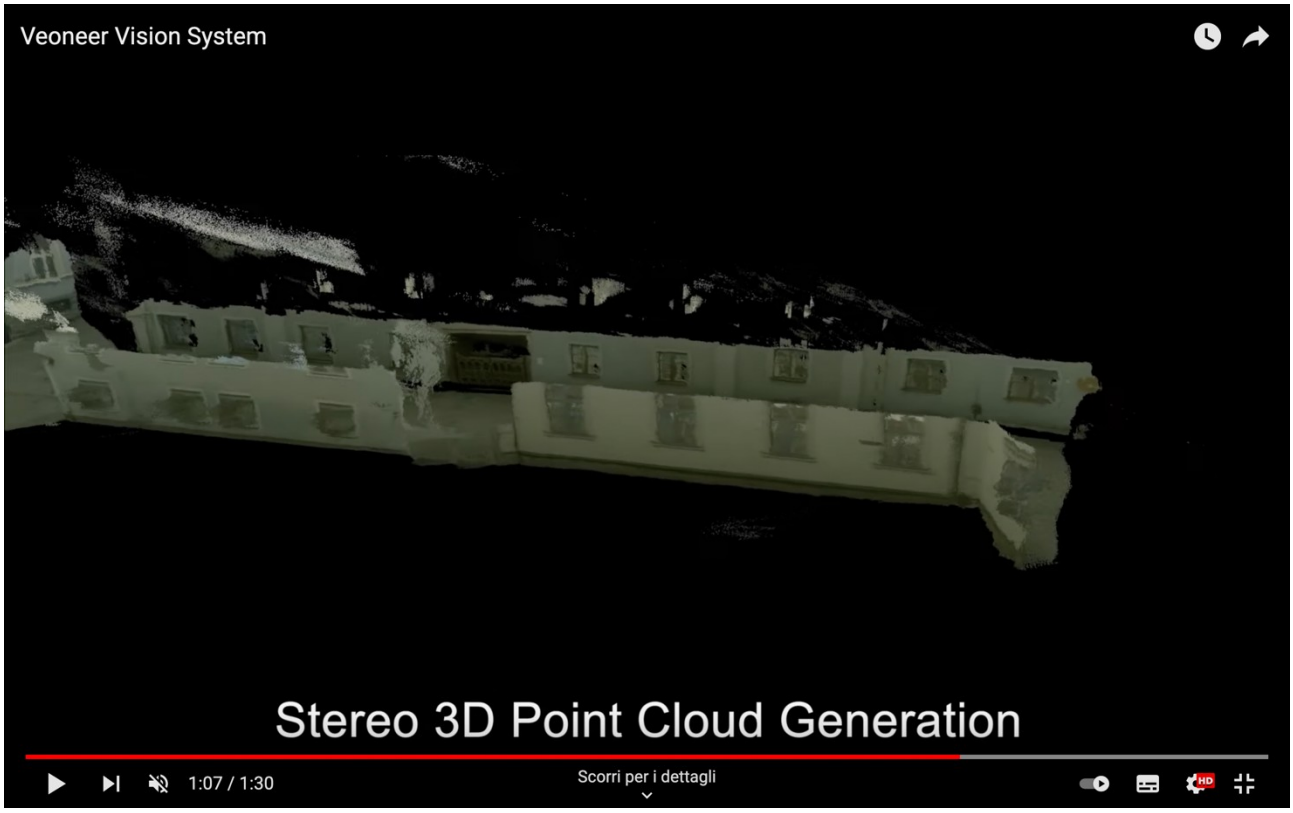




73. Veoneer (Sweden), https://www.veoneer.com/

Source: https://www.veoneer.com/en/technology

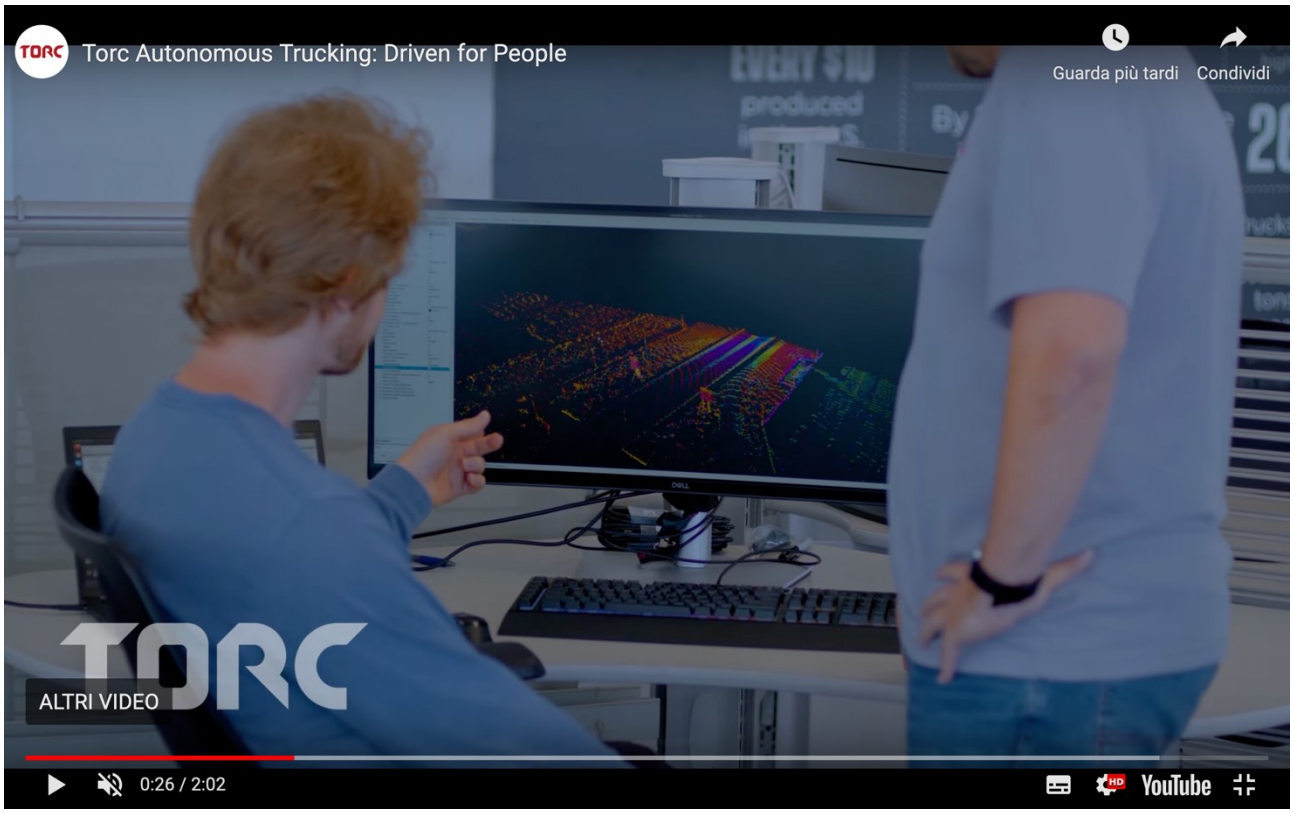




74. Torc Robotics (USA), https://torc.ai/

Source: < https://torc.ai/trucking/>

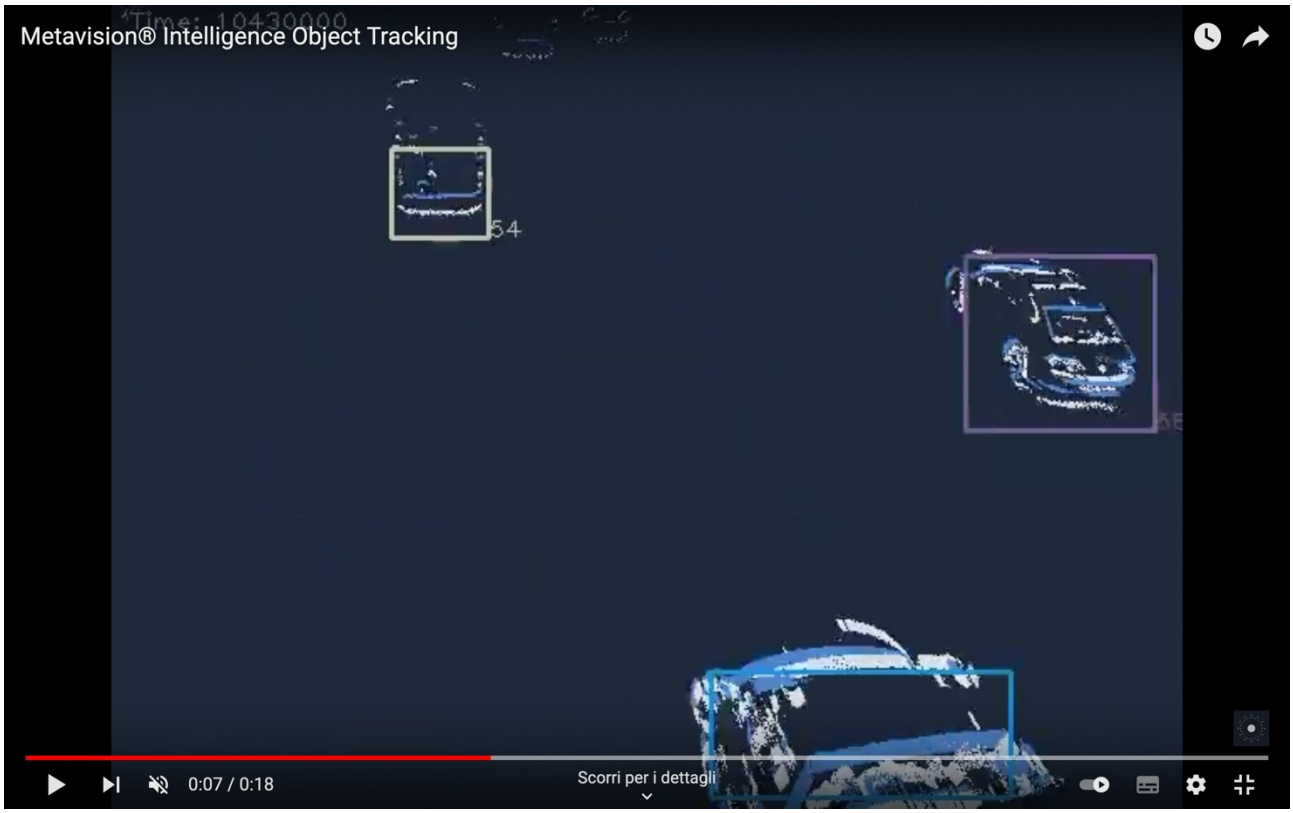

Torc Autonomous Trucking: Driven for People
Guarda più tardi
Condividi
TORC
ALTRI VIDEO
0:24 / 2:02
YouTube


Torc Autonomous Trucking: Driven for People
Guarda più tardi
Condividi
TORC
ALTRI VIDEO
0:26 / 2:02
YouTube



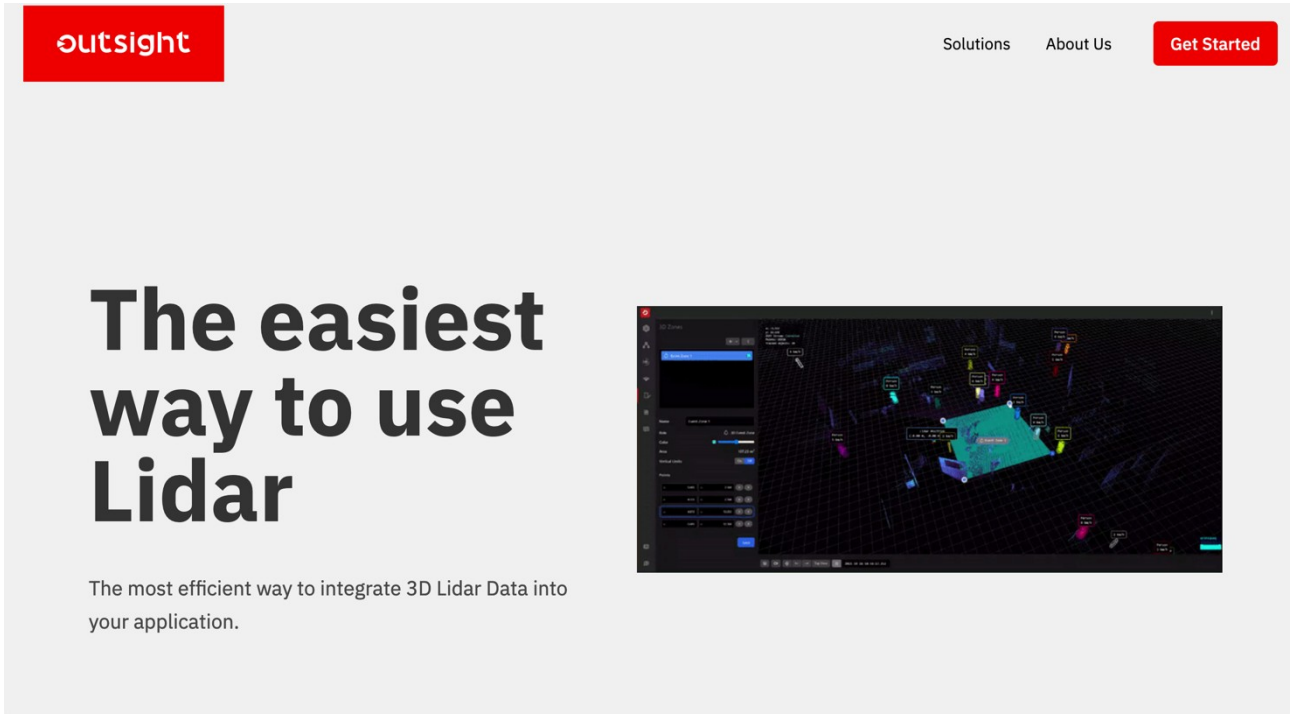
76. Prophesee.ai (France), https://www.prophesee.ai/

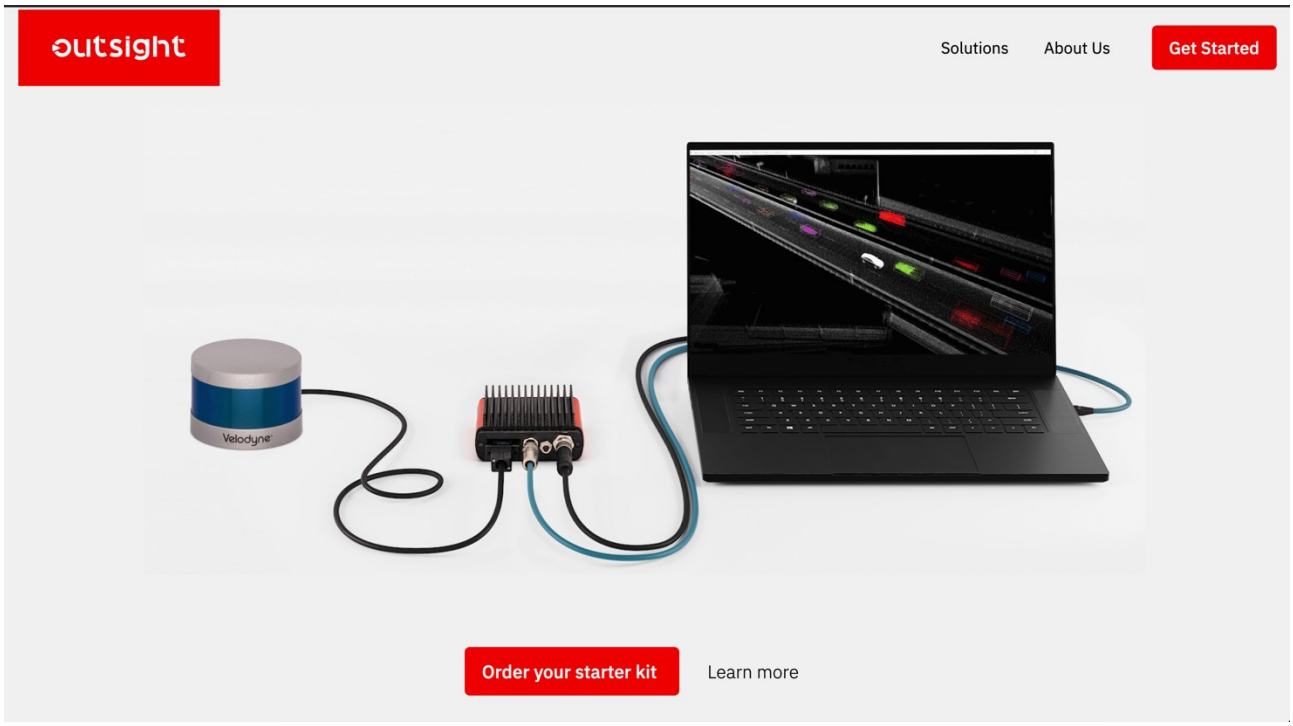
Source: <https://www.prophesee.ai/event-based-vision-applications/>



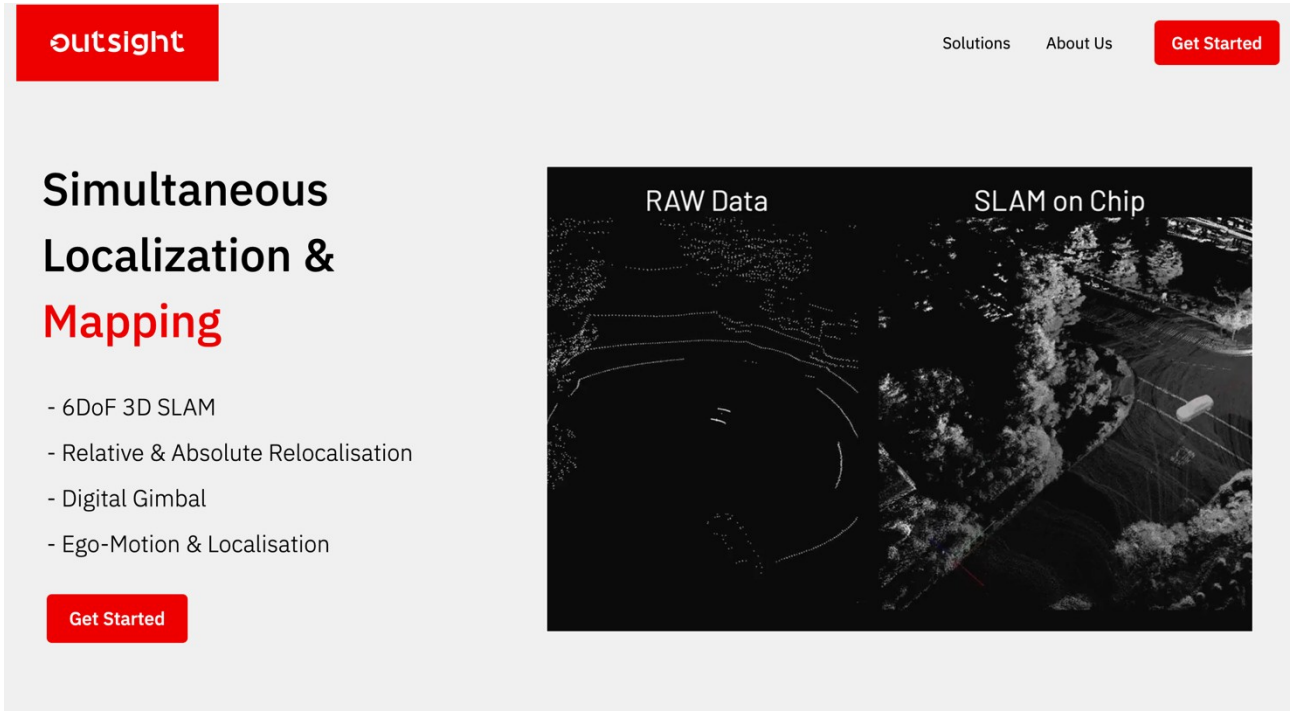
76. Outsight (Finland), https://www.outsight.ai/

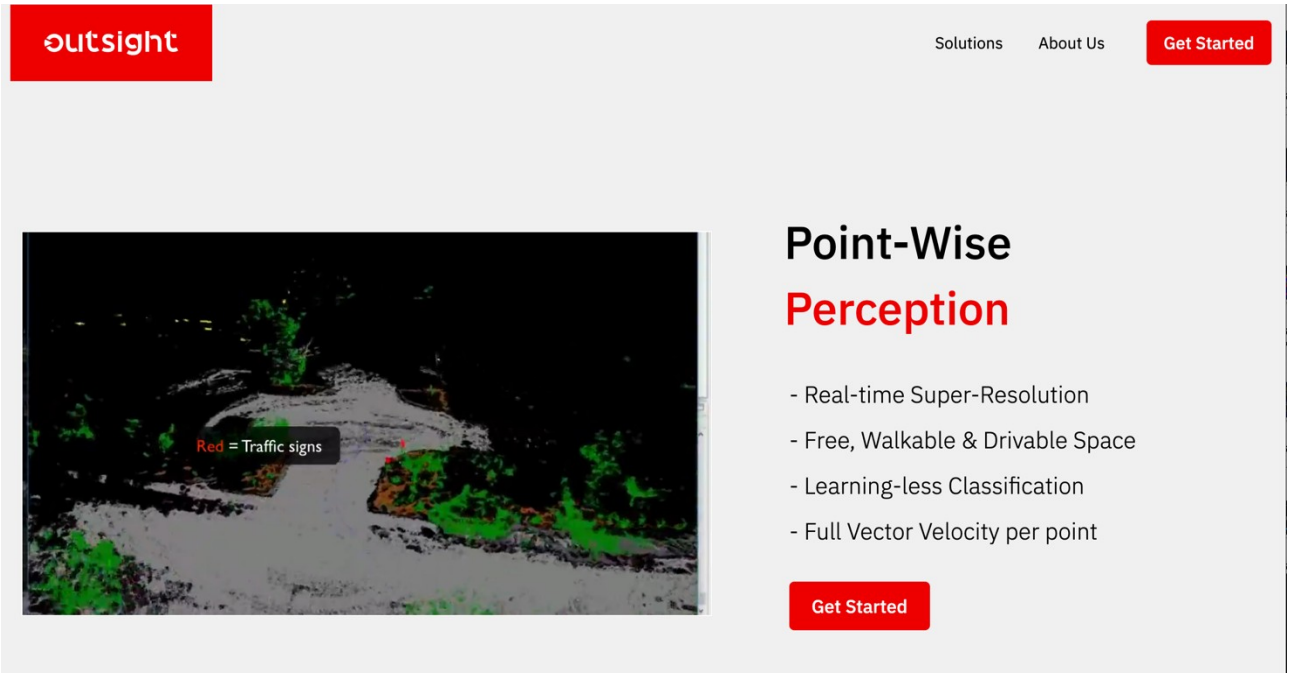
Source: <https://www.outsight.ai/>

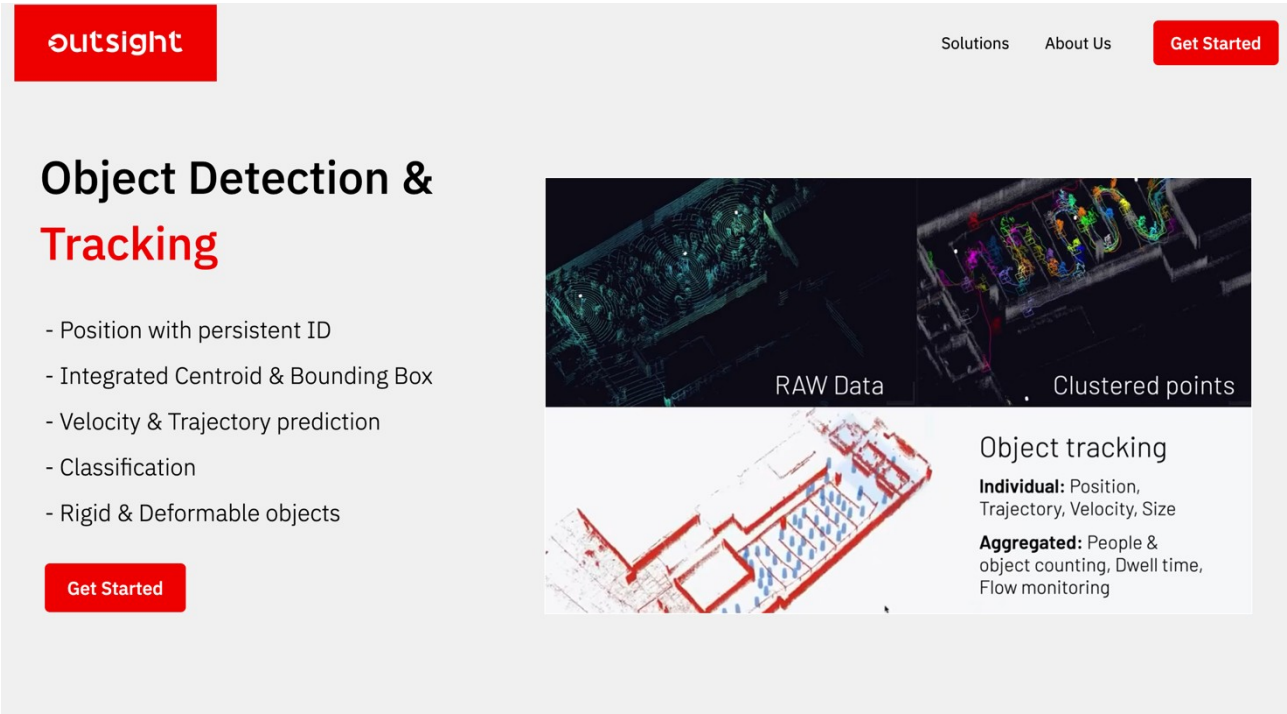




Source: < https://www.outsight.ai/features>





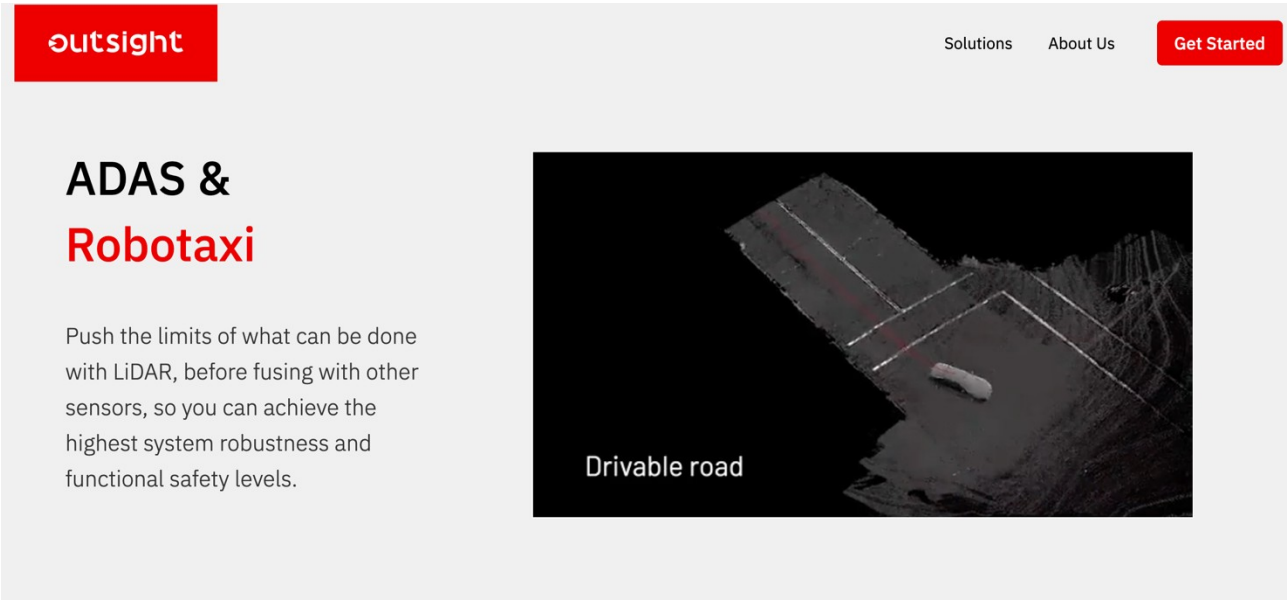


Source: < https://www.outsight.ai/smarter-vehicles-and-robots>

77. Dspace (Germany), https://www.dspace.com/en/ltd/home.cfm
No images available.

78. Hamamatsu (Japan), <https://www.hamamatsu.com/eu/en.html>
No images available.

79. Microvision Inc. (Germany), <https://www.microvision.com/>



80. Blickfeld (Germany), < https://www.blickfeld.com/>

Source: < https://www.blickfeld.com/case-studies/sachtleben-volume-measurement-with-lidar/>



Real-time volume measurement using LiDAR