Hive Mind:
The City in the Age of the Autonomous Automobile

by

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ABSTRACT

The adoption of autonomous vehicles and the integration of an internet-based general purpose technology platform into urban environments will catalyze the formation of a new system of automobility in the 21st century, subsequently necessitating the development of supporting architectural infrastructures. Using the City of Vancouver's transportation and planning mandate and present trends in urban planning as a framework, a scenario is generated for Vancouver, BC that re-imagines its downtown peninsula as a pedestrianized public realm serviced by autonomous vehicles via key routes. The new urban transportation model is supported by a system of intelligent, networked inter-system/modal hubs known as "Hives." This thesis specifically explores the potential of the Hive system as an integrated architectural-infrastructure that combines transportation, distribution, commercial and public activities into a modular, multi-scalar flow management structure capable of evolving, expanding and contracting as technological, economic and social conditions change through time.

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CHAPTER 1: INTRODUCTION

> The car is now the defining technology of our built environment. It sets the form of our cities and our towns. It dictates the scale of streets, the relationship between buildings, the need for vast parking areas, and the speed at which we experience our environment. Somewhere between convenience and congestion, the auto dominates what were once diverse streets shared by pedestrians, cyclists, trolleys, and the community at large. (Calthorpe 1991, 45)

When the automobile first appeared in the final decades of the 19th century, there was little way of knowing or imagining the world that would form around it. Certainly some - Karl and Bertha Benz, Henry Ford, Armand Peugeot - recognized the potential of the automobile to eventually replace the horse and transport the masses, but to the actual masses, the automobile was viewed with much more skepticism. It was fragile, where as a horse was robust. It required oil-derived fuel, whereas the horse needed only grass. The automobile required roads, whereas the horse could go virtually anywhere. Land based travel, had, for millennia be dominated by the horse and the automobile wasn't about to change that... But it only took 30 years for public opinion to change. By 1920, the automobile was well on its way to dominating land based travel and by the mid-twentieth century, the competing passenger rail and street car systems that had been built up over the previous sixty years were virtually dismantled in North America. The automobile's rise to dominance was not by chance, but was made possible though the design, cultivation and implementation of an extensive system of physical and social structures that in combination facilitated and perpetuated the automobile's use. This system is automobility.

As a large technical system, automobility is resistant to change but capable of it under the right social, technological and economic conditions. Within the system there are stakeholders dependent on its stability, examples include automakers, oil corporations, construction firms, steel manufacturers, traffic engineers, etc., that seek to maintain that stability. However, outside the system, there are forces that actively push for stricter regulations, advancement and change - the environmental protection agency, various environmental groups, politicians, corporate 'disrupters', planners and architects, etc... Between the push and pull of these forces, change takes place gradually, but detectably, over time. However under the right circumstances, a tipping point is reached and the system flips from one stable form to another, catalyzing the creative destruction of that which came before. It is under these circumstances that we presently find automobility - transitioning from an oil-based 20th century automobility to a 21st century automobility based on autonomous vehicle technology.

This thesis proposes that this transition does not represent the final form of automobility and that the system will continue to evolve as technology advances and interests outside of those within the automotive industry shape and limit the way the automobile is used, through the design and construction of supporting infrastructure and architecture. Given that the 21st century autonomous automobile will have a range of capabilities that far exceeds those of the 20th century automobile, a new supporting infrastructure will inevitably be developed in order to fully realize those capabilities. It is argued that the role and functionality of the automobile relates to and is limited by the systems in place which are designed to support it, and it is therefore not only possible to scale-back the extent of the automobile's range in urban environments via infrastructure, but also that it is this period of transition that is the opportune moment to do so.

This thesis tests this assertion through the development of an infrastructure system designed to support an urban model that prioritizes the pedestrian and active transit while limiting the unmitigated movement of the automobile. The site of this test originates at the downtown peninsula of Vancouver, Canada, as autonomous vehicle technology approaches ubiquity circa 2051. The system - dubbed the "Hive" - is technologically advanced, intelligent and adaptable, capable of mediating between the powerful external forces that shape the city - such as automobility - and the city's internal needs; examples including the management of automobile dependence, accessibility issues or reducing carbon emissions. The system is comprised of a network of inter-system/modal hubs (also referred to as hives) that are capable of coordinating their efforts to manage the flow of goods and people within the city while actively generating and preserving the conditions conducive to the evolution of a complex pedestrian realm.

In the initial stages of their implementation, individual hives are responsible for the coordination of movement, storage and charging of autonomous vehicles, connecting transit stations and modalities, and functioning as distributary nodes in the shipment of goods throughout the metropolitan area and beyond. Further programmatic function of Hives relates to, and compliments the surrounding context - examples include public, civic and commercial space, private storage, housing, public services, vehicle maintenance etc... The Hive network is designed to replace much of the static, specialized infrastructure that has been built to support automobility with an adaptable, generalized, connective system capable of responding to its environment through expansion, additive retrofit, contraction, and programmatic shift as the surrounding technological, social and economic context changes and evolves over time. Further, the Hive may be employed as an active agent of change, directing urban development towards a desired outcome through the introduction of program that works to either reinforce or counter developmental trends, such as the emergence of a creative district or gentrification. These capabilities, in addition to those relating to real-time flow management, are made possible through i) internet integration, ii) the deployment of autonomous vehicles as distributary, sensing and data collecting drones, and iii) the employment of a nested system of modular construction and automated methods of dis/assembly. Through the coordination of these technologies, the Hive network consciously works to assert active and public transit as the most convenient means of moving through the city for a controlling majority of travelers, thereby catalyzing the recession of automobility and the expansion of the pedestrian realm. The dichotomy that subsequently emerges between automobile space and pedestrian space positions the hive as a new interface within the city - a locus of spectacle, exchange and transfer between people, technology and the city's infrastructure.

The system of automobility

CHAPTER 2: AUTOMOBILITY

Contextualizing Change

According to the Intergovernmental Panel on Climate Change (IPCC), there is a small window of time in which the transition from an oil based economy to 'net zero' society can be made. By 2052 the Earth's average temperature will increase by 1.5°C above pre-industrial levels (IPCC 2018, 6). Limiting global warming to such will tangibly limit the ill-effects born from a disturbed climate system. Relative to a 2°C increase, global sea level will rise 10 centimeters less over the course of the 21st century, exposing 10 million fewer people to the associated consequences. Likewise, the risk of drought and heavy precipitation events will be lower and the effects of oceanic acidification and warming will be mitigated; decreasing the likelihood of wildfires, crop failure, famine, flooding, landslides, car accidents, fishery collapse, coral reef bleaching and so on... Limiting total warming to 1.5°C and avoiding these consequences (at least in part), requires immediately and rapidly transitioning to a global 'net-zero' society. Doing so, according to the IPCC, could stretch the cumulative carbon budget as far as 2050.

In order to meet the goal of a net-zero society, extensive changes will need to be made to present methods and patterns of energy production and consumption, land-use, urban planning and infrastructure. Integrated within each of these categories is the transportation sector. In terms of emissions generated by the movement of goods and people, transportation accounted for 20.5% of global CO_2 emissions in 2014 - approximately 7.2 million kilotons (World Bank 2014). However, this figure does not reflect the entirety of emissions that are systemic of the current, auto-centric, transportation model. Road construction, resource extraction and vehicle production are among the activities embedded within other categories, such as manufacturing, construction and mining. Therefore, more changes will need to be made than simply converting fossil fuel powered vehicles to zero emissions vehicles. Current systems will need to be modified considerably or entirely rethought, requiring global political, technocratic and individual cooperation and commitment.

The present transportation model is being reimagined at every level of government and from within the automotive industry. Across the world municipal governments are working to expand and improve active and public transit infrastructure in order to promote walking, cycling and public transit as alternatives to driving. Roads and, increasingly, entire areas within cities are being designated as car-free. The London Transport Strategy, for example, outlines a plan to ban automobiles from half the city's roads in the city centre by 2044 (City of London 2019, 111). Likewise, in 2018, Madrid designated the city center as largely car free, making concessions for taxis, zero-emissions delivery vehicles, public transit and car owners who live in the area (Jones 2018). In 2018 Oslo put forth a plan to completely ban automobiles from the city centre but later had to soften its strategy due to public pressure (Cathcart-Keays 2017). The city will instead ban parking but not total movement by automobile within the core. Within higher levels of government, efforts are also being made to force change. France, Germany, the UK, Denmark and the Canadian province of British Columbia have committed to a plan to ban the sale of fossil fuel powered vehicles by 2040 or earlier (C40 Cities 2019).

The bulk of the plans to curb transportation related emissions are aimed at the automobile and its supporting infrastructure. In recent years, increasingly critical discourse has emerged surrounding automobility. Bohm et al. have synthesized this critique as the four "antagonisms of automobility": (i) Automobility is a source of chronic congestion, its predomination as a means of individual mobility has resulted in collective immobility, (ii) automobility is ecologically unsustainable; it is a major consumer of non-renewable resources, a major source of pollution, its consideration dominates land-use practices, (iii) automobility is oil dependent and oil dependency is a geopolitical issue that a source of violence all over the world , and (iv) the deadly threat posed by the automobile is omnipresent, it is a major source of fatalities (Böhm et al. 2006, 9) . To completely address these issues, as is necessary, would result in the emergence of a new phase of automobility - a sort of automobility 2.0.

Automakers are aware of the critical discourse surrounding their product and are in the process of adapting their current business model to one centered around the production of electric vehicles and 'mobility as a service.' For example, the final generation of fossil fuel powered Volkswagens will be released around 2026, putting the complete phase-out of the internal combustion engine for the company somewhere around 2031. Likewise, Jaguar and Infiniti have started the process of phasing out the internal combustion engine; the transition should be complete by 2027 (+/-). Further, several new zero-emissions only automakers have formed in recent years, hoping to infiltrate the highly competitive automobile industry while there is a gap in the market and before the established manufacturers fully commit to electric vehicles. The most prominent and successful of these being Tesla –

arguably the instigator of the nascent ‘electric car revolution’ and the first to really prove the electric vehicle’s technical and market viability.

The growing popularity of electric vehicles – like those produced by Tesla – seems to indicate changing values surrounding automobiles and automobility. While ideas surrounding individual mobility and private property are still deeply rooted in Western nations (particularly North America), environmental, community and sustainability narratives are increasingly influencing people’s decision making. Growing acceptance of electric vehicles is one example of this. As is the growing number of people who choose to commute by active and public transit (it is acknowledged that this is also likely an economically driven decision). Car sharing is a third example, which, in recent years has become popular among those who may need a car, occasionally or regularly, but do not want the costs and responsibilities associated with its ownership. This model of use is becoming popular among urban millennials, a significant proportion of which who not only reject individual automobile ownership, but also many of the industries that were built by their parents’ consumption habits (McDonald 2015, 91). There is speculation that this generation of consumers will, as they age, grow to desire the same products that their parents did. However, it is also possible that a permanent split in tastes and spending habits has taken place (McDonald 2015, 97).

In response to changing values, tastes and spending habits, new environmental regulations and general critical discourse, automakers have fast-tracked the development of a new model of automobility centered around autonomous vehicles. More efficient, safer, cleaner, quieter, sharable, connected and intelligent – autonomous vehicles (or 'driverless' cars) promise to address many of the shortcomings of the present system by integrating several new technologies into the automobile: (i) a suite of sensing technologies that will make the vehicle capable of navigating its environment, (ii) a system of artificial intelligence capable of deep learning, and (iii) the integration of internet connectivity making the vehicle capable of establishing a communication link between itself, city infrastructure and personal devices such as mobile phones. In combination, these technologies will future-proof the automobile, rendering it capable of filling a range of roles much more diverse than it currently does. In addition to functioning as the means by which people and goods move from one place to another, the automobile will replace the human as the active agent, interface and gate-keeper in delivery and transportation scenarios – such as taking a taxi or having groceries delivered. Many of the present human – human interactions, such as those that occur between a passenger and the taxi driver or between a transport truck driver and a warehouse worker, will be replaced by human – automobile, automobile – automobile, robot – automobile or even building – automobile interactions. For automakers, transitioning to this new form of automobility not only preserves their viability as a business model by doing their part to avert environmental and - potentially – societal collapse, it vastly expands the market for automobiles through the fabrication of new relationships between people, technology and the environment.

For more than a century, the city has been evolving in lockstep with automobility. Highways, hierarchical street networks, driveways, garages, parking lots, car washes, fueling stations and repair shops are examples of infrastructure that were developed specifically to facilitate automobile use. Inventions such as drive-thrus, drive-ins, urban sprawl and the suburbs grew out of the lifestyle that the automobile promoted. Therefore it can be concluded that the new capabilities of the automobile will inspire the evolution of the city through: i) infrastructural development, and ii) changes in human lifestyle and habits. Therefore, it can also be concluded that cities have a part to play in narrating the functional and cultural role of the automobile by deciding what sort of supporting infrastructure is built.

This thesis proposes that automobility is part of a larger system in a constant state of technological and cultural flux, that the new regime of automobility will not be its final form, and that evolution within the system brought about both disparate and interrelated political, technological, economic and cultural forces will require adaptation. In response, this thesis proposes a new public infrastructure and urban system that connects urban systems and adapts to changing economic, social, technological contexts through architectural components and programmatic parts. It utilizes the Hive, both a building and a network, capable of integrating into a city's various systems - transportation, distribution, commercial, entertainment, agricultural, etc... in order to function as a inter-system hub capable of both driving change and maintaining equilibrium in accordance with the needs of the city. This thesis tests the potential of the Hive system in the Canadian city of Vancouver, British Columbia to create a pedestrianized core as part of the city's plan to reduce automobile use and promote active and public transit in the age of the autonomous automobile.

Automobility in the 20th Century

When the automobile emerged as a new form of transportation around the turn of the 20th century it converged with a new source of energy and new methods of communicating. Together, the automobile, oil, centralized electricity, the telephone and the radio formed a general purpose technology platform; a new foundation for social and economic life in the 20th century (Rifkin 2017). The relationship that evolved between the economy and the automobile was mutualistic. The growth of the economy was dependent on the flexibility and speed of the automobile. While the mass appeal of the automobile was dependent on the expansion of the middle class via the economy's growth. For both, the key was to design and construct an infrastructure system that would allow the automobile to reach its potential as a flexible and personalized means of transporting goods and people.

Defining Automobility

Automobility can be defined in two ways; the first understands automobility as the combination of autonomy and mobility (Freund et al. 1993, 111). As such, autonomy invokes notions of individualism and self-determination, while mobility speaks to the idea of free movement, in terms of space as well as between the levels of a stratified society (to be upwardly mobile).

A second definition of automobility refers to the system that has evolved around the automobile in order to make its use possible. Automobility in this sense is " [the] set of political institutions and practices that seek to organize, accelerate and shape the spatial movements and impacts of automobiles, whilst simultaneously regulating their many consequences" (Böhm et al. 2006, 3). Within this definition it is suggested that the automobile does not inherently possess the qualities of automobility. Rather, the qualities of autonomy and mobility have been attributed to the automobile through the deliberate and strategic development of a supporting socio-technical infrastructure by political and technocratic forces. Freund et al. summarize this infrastructure as composed of the following: (i) a qualified driver, (ii) "an extensive network of roadways," (iii) "a legal, social and technical system of operational controls that manage traffic," (iv) "storage facilities for autos when they are not in use," (v) "supporting infrastructure of service, repair, junking, and fueling facilities," and (vi) a network of "production and distribution facilities" (Freund et al. 1993, 111). Therefore Automobility is a complex set of entwined factors having social, political, technological, economic and physical (vehicle, infrastructural and architectural) components.

Automobility as a Complex System

Automobility evolved over the course of the 20th century, spreading from America and Europe to nearly every inhabited corner of the world. With its adoption eventually comes a state deep integration into the culture and economy of the area. In order to understand the nature of this integration, automobility can be conceptualized as a complex system (Urry 2004).

The elements of complex systems include:

• Many parts: Automobility is comprised of political, technological, economic, cultural, infrastructural elements. Each of these elements are comprised of subsystems at various scales (local - global).

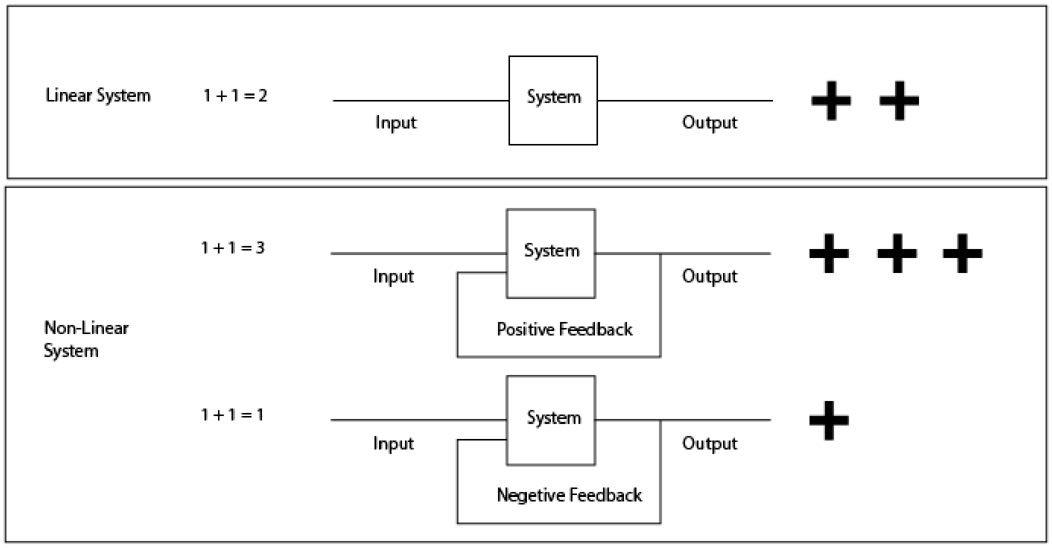

Diagram of linear and non-linear systems. Linear systems are characterized by outputs equating to the sum of the parts. Non-linear systems characterized by positive feedback systems grow through efficiencies that result from interactions between inputs and existing components. Non-linear systems characterized by negative feedback systems contain mechanisms that maintain a state of equilibrium by countering system inputs that would disrupt the equilibrium.

• Parts are interrelated, interconnected: The elements of automobility influence each other, they do not exist in isolation. Interaction takes place between elements at nearly every scale.

Due to these two factors small changes can result in large changes.

Complex systems expand and contract non-linearly (1+1=3) and they do not equal the sum of their parts (1+1=2). Non-linear change is the result of efficiencies within the system that reinforce patterns through the layering and interrelation of feedback loops - where negative feedback loops maintain stability as positive feedback loops reinforce change. While change is more dramatic in systems characterized by positive feedback regimes, stable systems are not static. Local scale change within these systems builds and radiates, until the right mix of political, cultural, economic, technological and infrastructural forces destabilize the system resulting in the complete or partial disassociation of elements.

Automobility as an Autopoietic System

John Urry conceptualizes automobility as a non-linear, autopoietic system that is made up of "cars, car-drivers, roads, petroleum supplies, [various] novel objects, technologies and signs" (Urry 2004, 27). Autopoietic systems are those in which the processes that take place within the whole produce the individual elements and sub-systems that recreate it, allowing for the system's growth, evolution, self-reparation. As an autopoietic system, automobility grows and expands by critically integrating into various systems - transportation, social and economic. Within these systems, automobility's advocates and stakeholders act in ways that grow the system.

A System of Parts

Over the course of the 20th century the global scale adoption of the automobile as a means of transporting people and goods was made possible through the development of a standardized infrastructure. This infrastructure can be broken down into component groups that are physical/built, legal, economic and cultural in nature. Of these, only a few of the physical components are absolutely essential to the basic function of the automobile while the others serve to perpetuate automobility. The component groups can be categorized according to their role within the system. The physical and legal component groups are considered to play a role that supports the basic function and safe operation of the automobile whereas the economic and cultural component groups work to reinforce the automobile's role within the transportation system and culture.

What becomes apparent upon organizing the component groups into physical, legal, economic and cultural categories is that automobility is an incredibly robust system with many stakeholders. Affecting automobility from the outside will likely result in slow change, if any at all as there are backup mechanisms that will repair any damage that is done to the system. If swift change is to be made, effort must be directed towards the structures that are most fundamental to the automobile's function: roads, fuel networks and storage.

1	**Automaker**	
	Design Research Testing Manufacturing Assembly	Product Planning Marketing Lobbying Assembly Plants Workers

Role of the Automaker: As the designer and manufacturer of the automobile-object, the system of automobility begins with the automaker. Relative to the larger system however, the role and responsibilities of the automaker are small.

2	**Supporting Infrastructure**	
A	**Physical**	
(i) Primary	Hierarchical Road Network Fuel Network	Storage
(ii) Secondary	Automobile Dealerships Automobile Rental Networks Transportation Networks Maintenance Facilities Parts Networks	Recycling/Junking Facilities Traffic Control Centres Road Signs and Signals Department of Motor Vehicles
(iii) Tertiary	Motels and Hotels Regional, Provincial, National Parks Drive-Thrus Drive-Ins	Suburban Development Race Tracks Shopping Malls

The Physical Infrastructure of Automobility: The primary physical infrastructure is most critical to the basic function to the automobile - it cannot function without it. Secondary physical structures describe the channels of distribution, sales and maintenance that are needed in order to transfer ownership of automobiles from the automaker to the consumer and keep automobiles in safe running condition. Tertiary physical infrastructures relate to and support the legal, cultural and economic component groups of automobility.

2	Supporting Infrastructure	
B	**Legal**	
(i) Primary	Traffic Laws Licensing	Vehicle Registration Ownership
(ii) Secondary	Insurance	Leasing
(iii) Tertiary	Legislation, Standards and Regulation Emissions and Safety Testing	Traffic Engineering Urban Planning

The Legal Infrastructure of Automobility: The primary legal structures make collective use of the automobile possible, they create a structure for its safe use. Secondary legal structures facilitate the purchase and ownership of automobiles. Tertiary structures are responsible for the advancement, regulation and maintenance of automobility

3	Reinforcing Structures	
A	**Cultural**	
(i) Primary	Cruising Shows and Rallies Road Trips	Camping Sunday Drive Automobile Racing
(ii) Secondary	Maintenance	Modification
(iii) Tertiary	Commuting Road Rage	Local Conventions and Attitudes (Driving

The Cultural Structure of Automobility: The primary economic structures integrate the automobile into economic life. Secondary economic structures are comprised of systems of workers that are employed within the transportation industry that depend on the automobile for work. Tertiary economic structures are comprised of a system of workers that regulate, maintain and advance the system of automobility.

3	Reinforcing Structures	
B	**Economic**	
(i) Primary	Distribution of Goods	Transportation of People
(ii) Secondary	Transit Workers Delivery Drivers	Taxis Mail Delivery Workers
(iii) Tertiary	Planners Engineers Politicians Lobbyists	Designers Financiers Insurance Brokers Construction Workers

The Cultural Structure of Automobility: The primary cultural structures are those events, or activities that elicit positive feelings towards the experience of driving automobiles. Secondary structures establish a physical connection between the owner and the automobile and instill a sense of pride while reinforcing notions of private property. Tertiary structures relate to the patterns of behaviour that evolve from automobile use that are reinforced through collective display.

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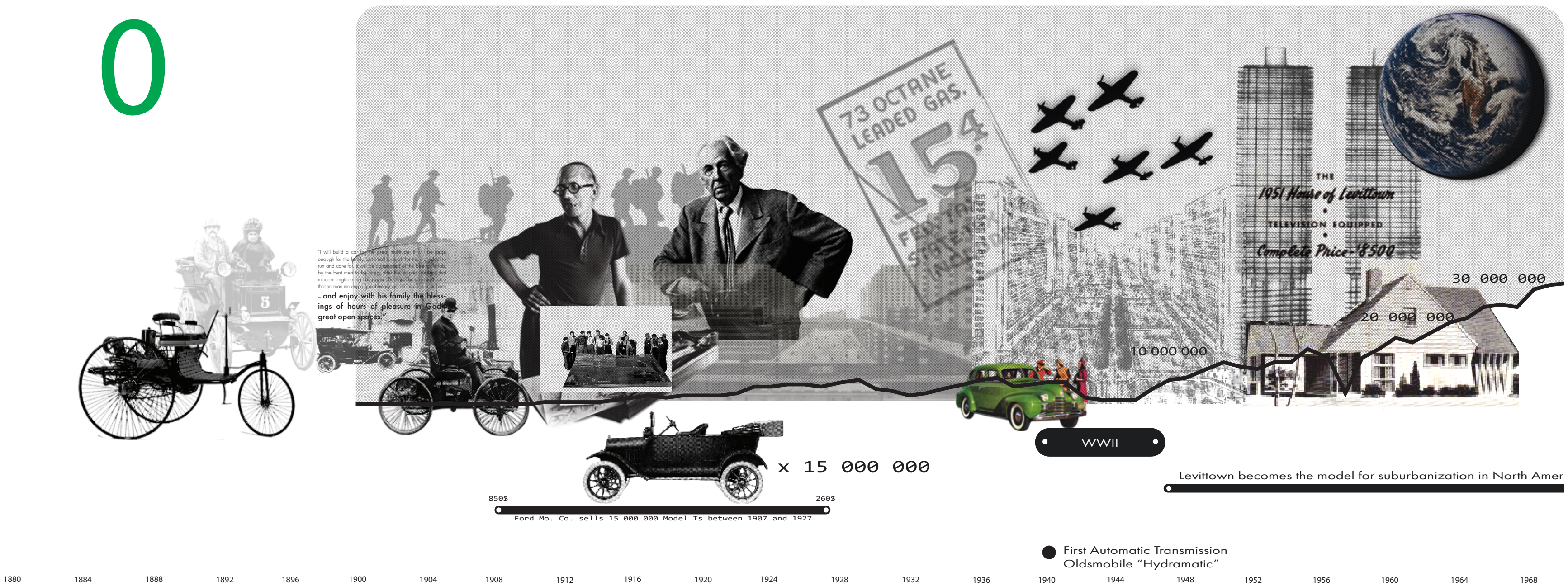
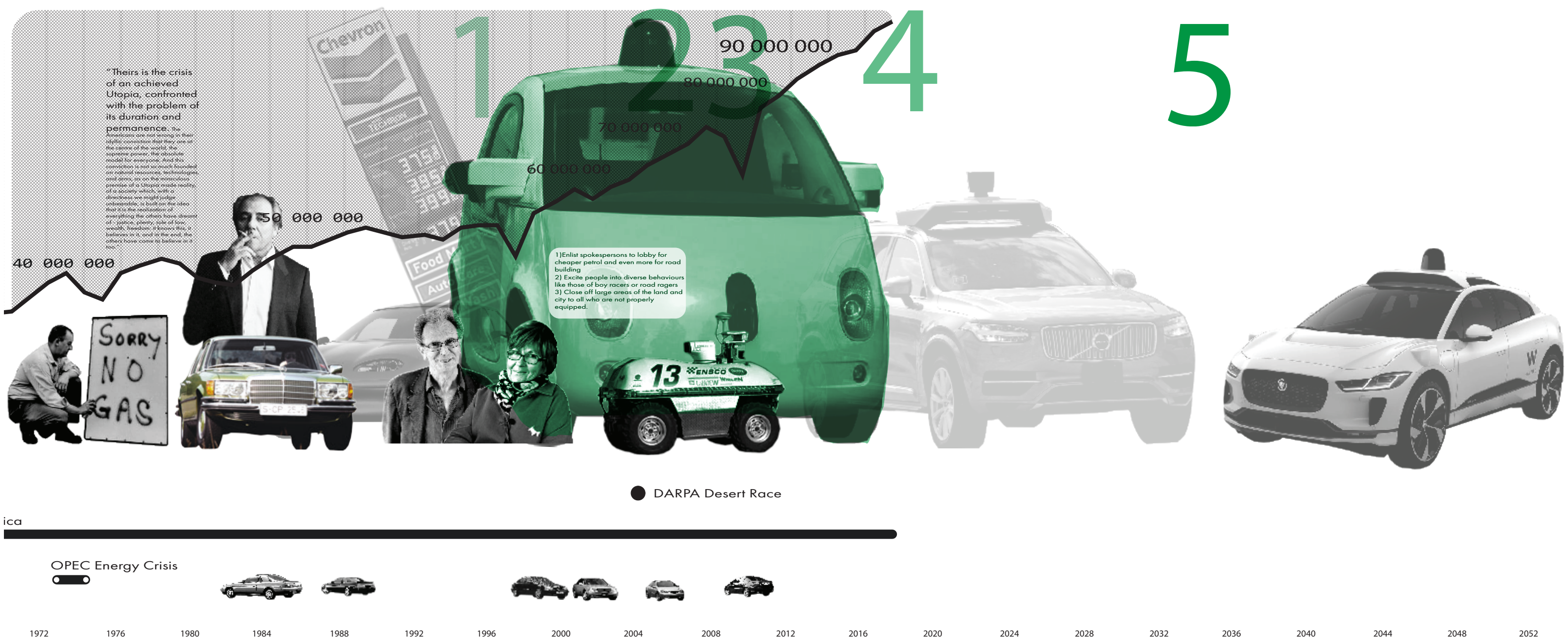
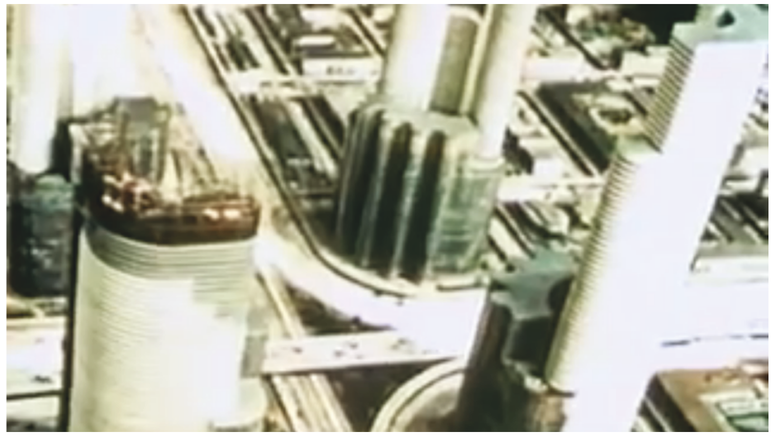


The first automobiles emerged in the final years of the 19th century. The 'oil and steel' automobile ultimately beat out the electric and steam-powered autos that were also common in the early years of the automobile. Economies of scale through the refinement of assembly line manufacturing process made the automobile affordable for the general public. Affordability contributed to the automobile's wide-spread adoption and eventual predominance as a mode of transportation. The timeline tracks the rise of the automobile to predominance and its influence.



The automobile’s road to autonomy. Since the 1990s when the first GPS navigation system began to appear in automobiles, the vision of the autonomous vehicle has come closer to being a reality. Radar guided cruise control, surround view camera systems and various driver-assist mechanisms became common place in the late 2000s. In 2019, Waymo became the first to put autonomous taxi cabs into circulation for paying customers.



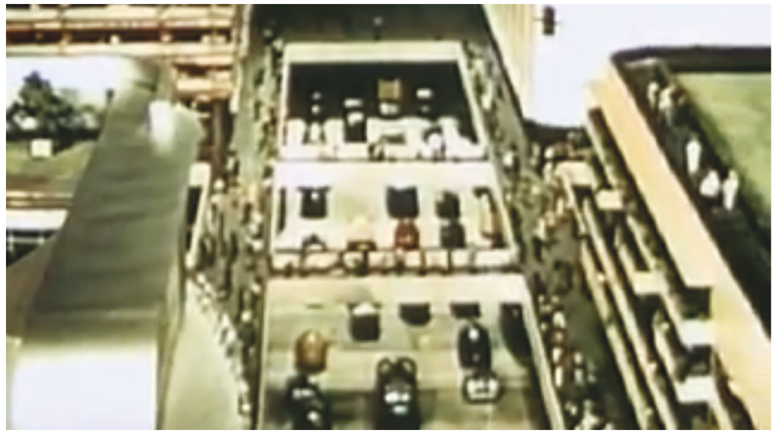
Video still from 1940 film, *To New Horizons* (1940), GM Futurama

The Reproduction of Automobility

A Vision For Progress

The experience of the automobile – driving it, riding in it, owning it – legitimized the notion that the automobile embodied freedom, movement, progress and autonomy. Through the act of driving, according to Latimer, the driver is able to "momentarily and provisionally... dwell in the future;" and by entering the larger embodiment of automobility, they are able to experience "freedom, flexibility and mobility." (Latimer 2006, 41). The capacity of the automobile to render its pilot and passengers free, mobile and autonomous citizens generated a sort of equivalency between automobility and a utopian state, where possessors of an automobile were also possessors of freedom, autonomy and mobility. It follows that if everyone possesses an automobile, then everyone possesses these qualities.

The automobile then provided a way to progress and advance society. If freedom was achieved through automobility, then it was imperative that every citizen possess an automobile. This logic inspired the re-imagination of the city centered around the automobile and the automobile provided a



Video still from 1940 film, *To New Horizons* (1940), GM Futurama

tangible, but compelling object with a relatively clear set of limitations and purposes around which the future of the city could be imagined. These limits can be distilled to the following : the automobile carries people and their things, it requires energy to power its motor to turn its wheels, its range of motion is limited by the geometry of its wheels, and its efficacy is relative to the surface with which those wheels are in contact. Designing the city around these limitations provided a clear way forward.

The "To New Horizons" exhibit produced by GM for the 1939/1940 Worlds Fair is perhaps the clearest vision of the auto-centric city. The exhibition features a model of the city of 1960 – a completely modernized city designed around automobility that coherently synthesized ideas that had been presented by Hilberseimer's Vertical City and Corbusier's Ville Radieuse while also building on some of the ideas presented in the 1927 film Metropolis.

The primary organizing feature of the city is a gently arcing freeway, flanked on either side by skyscrapers "a quarter mile high." In this vision of the city, residential, commercial

Video still from 1927 film, *Metropolis*, directed by Fritz Lang

and industry have been separated "for greater efficiency and convenience." Elevated sidewalks cantilever over the street below, effectively doubling the space available to the automobile and creating a safe environment for pedestrians to navigate above. This prototype of the automobile city provided a map for the city of the future. The "To New Horizons" exhibit synthesized the system of automobility into a clear and executable vision for the immediate future. It solidified the place of the automobile through the presentation of a compelling overture of what was possible if the city were designed around the automobile.

Video still from 1927 film, *Metropolis*, directed by Fritz Lang

Integration into Economic Life

The integration of the automobile into the market economies of the West in the first half of the 20th century initiated the evolution of a set of mutualistic relations between the economy and automobile. In Europe and particularly, North America, the automobile, in its various forms, was promoted as a flexible means of transporting goods from point of production/extraction, to transformation, to sale or to shipping port. The capability of the auto to transport commodities long distances at high speeds was embraced

The multi-functional street - Narrator: "Vegetables and people wilted under the blazing sun and the kids were hard boiled." Video still from *The American Road*

The automobile replaced competing transportation systems over the course of the 20th century, creating economic dependence on the automobile. Video still from *The American Road*.

by the free market. Economic activity gradually began to reflect the capabilities of the automobile and the pace at which it operated (Urry 2004, 27). After more than a century of co-evolution, automobility cannot be disentangled from the market economy.

In much the same way that the economy became dependent on the auto, the auto became dependent on the economy. The expansion of the market economy, for which much of the credit can be attributed to the automobile itself, gave rise to the working middle class. Automobility was (and is) dependent on this demographic's demand for automobiles - but their demand for automobiles was (and is) dependent on the strength of the economy. By fueling the expansion of the economy, automobility, in effect, created the conditions for its own expansion.

Integration into Social Life

As automobility was adopted by the masses, it altered the way people perceive and relate to space, time and one another.

The transformation of the city into an environment suited to use by automobiles was integral to its economic integration. (Video still from *The American Road*.)

The unpaved roads that were navigable by horse and carriage were not well suited to the automobile. The construction of paved roads was the first step to integrating the automobile into economic life (Video still from *The American Road*)

First, automobility transformed the way people perceive space. The automobile's ability to perceptually compress space made it possible to live and work in distant areas of the city (or different cities altogether), to travel for recreation and to maintain familial ties or friendships across great distances (particularly in combination with the telephone). It allowed people to live a lifestyle centered around spatial and social mobility - they could be who they imagined themselves to be and were not tied to any particular place or its limits.

Automobility likewise altered temporal consciousness (Urry 2004, 28). Unbeholden to the schedule of a train or a street car or temperament of a horse, people could leave and arrive according to their own schedule. If running late, the automobile made it possible to make up for lost time. If there was time to waste, the automobile provided the entertainment. Automobility made time flexible - stretchable, compressible. Rendering time (almost) totally flexible gave people choice and therefore freedom to live their life according to their own vision.

The Automobile played a role in democratizing leisure time in the 20th century. Working class people could enjoy many of the same activities and places that were previously only accessible by elites. (Video still from *The American Road*)

New ways of socializing centered around the automobile emerged as the automobile grew in popularity. The Sunday drive was a way for the family to enjoy quality time together, the drive-in theatre and the drive-thru restaurant were popular destinations for date-nights, cruising the strip became part of the public spectacle, and the road trip became a way to connect with the land and its origin myths. Automobility facilitated the formation and reinforcement of friendly, romantic and familial bonds by providing an environment to share experiences and form memories.

Automobility is a form of semi-private, mobile dwelling. It is among the only privately owned objects that are permitted to permanently occupy the public realm without question. (Video still from *The American Road*)

Automobility made it possible for people, if they so chose, to transcend their socio-economic class. They could go anywhere, do anything, be anyone. This, along with the flexible lifestyle that automobility made possible, generated tremendous value in people's personal lives, in turn, inspiring them to advocate for the expansion of the automobile system. This advocacy translated into support for infrastructure projects that made automobile use more efficient and expanded the freedoms of its users. The expansion of

The drive-in theatre reinforced the system of automobility by integrating the automobile into social and leisure activities.

automobility meant the expansion of possibilities - more places to go, more people to see, more people to be.

Adaptable Assembly

The automobile is designed as an assemblage of pieces, some proprietary, others universal. It can be assembled in one part of the world to be sold on the other. It can be made new, piece by piece as each degrades over time. As put by Urry (2004), the automobile is the "quintessential manufactured object" (25).

The versatility of the automobile's assembly process makes it adaptable to changing demand, both in terms of sales and consumer preferences. It is common practice among automakers to update models every 2-3 years - the midpoint in a product's life cycle - making changes to the elements that prospective buyers can see and touch while most of the underlying mechanicals continue unchanged. As a result, the automobile appears to be constantly evolving, rendering its former form and its competition obsolete. The

The process of assembly that has co-evolved with the automobile contributes to the system's adaptability. Interchangeable parts simplify the process of repairs and updates. (Video still from The *American Road*)

The automation of repetitive and dangerous tasks reduces strain on workers, making it possible to produce more automobiles in less time. (Video still from *The American Road*)

appearance of newness and superiority generates demand, thus perpetuating automobility.

Realization

The integration of the automobile into social and economic life in combination with the methods of assembly employed by automobile industry and the projection of ideals relating to freedom and mobility onto the automobile by its various advocates and stakeholders, all work together to create the autopoietic system of automobility, which, through the collective interaction between various physical, legal, economic and cultural structures is made possible.

What this thesis proposes is that there is nothing about automobility that is inherently fixed - that it changes and can be changed through various pressure points from within as well as from without of the system. What exists presently exists because it was cultivated through the collective action of various actors that believed in the value of the system

The character of the infrastructure that is built to facilitate the use of the automobile defines and limits the way the automobile is used. (Video still from The American Road)

and way of life they were creating. It is possible then, that a compelling vision for a new way of living could initiate the transformation of the present system into something much different.

Drawing exploring the future of mobility as a service and the potential of the automobile to function as a sensor and data collector. Collected data is used to gain information about flows within the city. This information is used to make planning decisions, identify trends and generate strategies (Illustration adapted for City of Vancouver Archives).

Automobility in the 21st Century

General Purpose Technology Platform

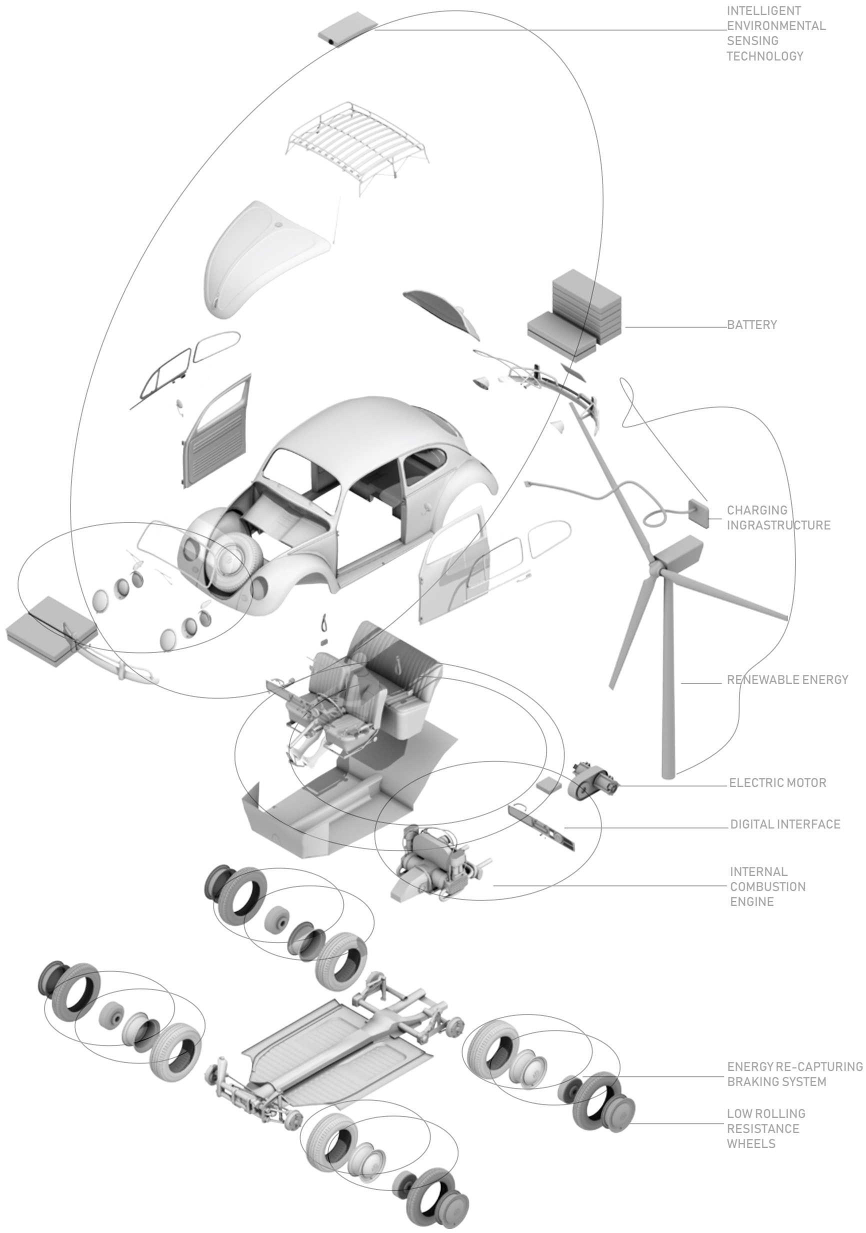
Just as the ‘steel and oil’ automobile was a critical component in the development of the 20th century general purpose technology platform, the autonomous automobile is critical to that of the 21st century. The analogy extends further in that once again, the implementation of a new platform will underpin a new set of social and economic relations - this time based on sharing economy and three internets (Rifkin 2017):

• Communication internet: facilitates the sharing of data, words, information, media and ideas over the World Wide Web between people and objects

• Energy internet: facilitates the sharing and distribution of energy from renewable resources across a decentralized smart grid

• Transportation internet: facilitates the movement of goods and people using autonomous vehicles

The implementation of a new general purpose technology platform will present new opportunities for architecture and urban design. Both the technology itself and the social adaptations that are made will impact the organization of cities, land-use policies and practices, architectural programing and systems integration. Likewise, it will make it possible to develop an architecture that is capable of communicating with its environment, responding to it, and adapting to it; creating a way of living almost unrecognizable from that of today.



The automobile as an assemblage of parts, many of which are designed to be interchangeable with replacement parts at a future point of failure. Automobiles are designed to be retrofit with new parts as they age and technology advances.

Transition

Transition research seeks to understand the relationship between phases of transition and the properties of socio-technical systems. It understands transition as a process that can be driven once a particular assemblage of technologies, infrastructures, social conditions and economies are in place (Temenos et al. 2017, 114). When the relations between these elements are understood, missing elements can be introduced, or existing elements modified in order to induce transition, enabling decision makers to drive change and shape the system.

Urry proposes that in order to shift to a new system of automobility, the system must be changed from within. He puts forward six socio-technical transformations that will catalyze a tipping point (Urry 2004, 33). This thesis has added two transformations to the list that will significantly impact automobility as they are implemented (vii and viii).

i) New energy sources/power units (33): Nearly every major automobile manufacturer has plans to introduce a fully electric vehicle or electric model lineup. Manufacturers such as Jaguar and Infiniti have committed to plans to introduce only electric vehicles by 2025. Several newcomers to the automobile industry have emerged that produce only electric vehicles (ex. Tesla). The transition from petrol power cars to electric cars is taking place at all levels within the automobile industry – personal (cars and motorcycles), public (buses) and delivery (vans and semis).

ii) New Lightweight Materials (34): Aluminum is replacing steel. In 2016, the Ford F-150 was introduced with a body made entirely of aluminum. Ford sells nearly 1 million (or more) F-150s annually. Likewise, carbon fiber is becoming more common as automakers develop new ways to mass produce the material. The BMW i3 is the first mass production vehicle to be built entirely of carbon fiber. Lightweight materials contribute to reduced energy consumption and improved performance in terms of handling and acceleration. Lightweight vehicles require less powerful motors.

iii) “Smart-Card” technology (34): Mobile phones are now capable of locking/unlocking as well as starting a vehicle remotely. They can also be used to park the vehicle, adjust the climate controls, close/open the sunroof or windows. Mobile phones now have the capability of functioning as a bank or credit card, electronic tickets.

iv) De-privatized model of use (34): automobiles are being de-privatized through carsharing, car clubs and car-hire schemes. IT companies such as Uber and Lyft have upended the traditional taxi model, which at this point in time looks as though it may fade from existence all together in the coming decades while apps such as Turo make it possible for car owners to rent their personal vehicle to other users.

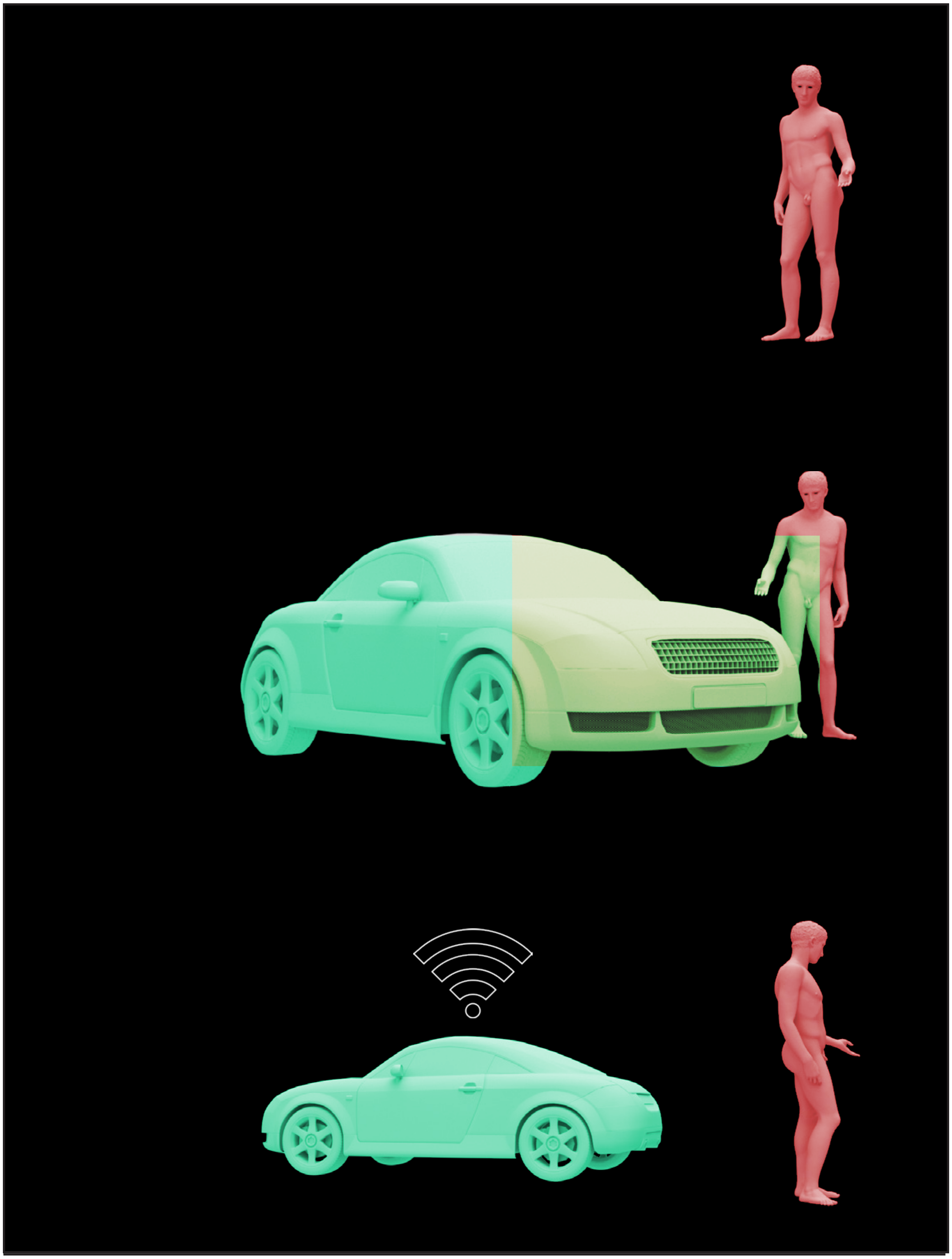
v) End of predict-and-provide service (34): involves the development of policy and infrastructure changes that shape behaviour rather than trying to predict behaviour and provide a service. Examples of policy that shape behaviour include efforts to make automobile use less appealing such as fuel taxes or congestion charges as well as those that make alternatives more appealing, such as expanding public transit service or cycling infrastructure.

vi) The internet of things (35): interconnection via the Internet of computing devices embedded in everyday objects, enabling them to send and receive data.

vii) Autonomous vehicle technology : the human driver is being replaced with a system of hardware and AI software capable of deep learning in addition to sensing and communicating with its environment. The complete implementation of AV technology will result in new relationships between objects and their environment.

viii) 3D Printing and automation in production – 3D printing and automation technologies will upend the current manufacturing process. These technologies will depend on considerably fewer employees and will largely eliminate the need for sheet metal and stamping in factories. The production process will reach unprecedented levels of flexibility.

Given that many of these transformations are already a reality and in the process of widespread adoption, automobility has reached the tipping point. It is therefore of interest what the future of automobility might look like and how it will affect urban environments.



Automobility has passed through three phases: i) pre-automobility, ii) 20th century automobility, and iii) 21st century automobility

CHAPTER 3: METHOD

Developing a Scenario

Scenario method is a means of defining a potential future based on the projection and analysis of influential trends and factors of inertia (Horwath 2006). Once defined, this future provides a plausible contextual framework in which to work. For the purpose of imagining how the city and the automobile could co-evolve over the next several decades, the scenario constructed here combines four major topics:

Automobility

i) The historical development of automobility and the theory of autopoietics

ii) The developmental trajectory of the automobile as well as the general purpose technology platform

The City

iii) Trends in urban design, most notably the pivot from auto-centric urban design and transportation policy to people-centric design and policy

iv) Vancouver's transportation and developmental plans for the next 20 years

Topics i and ii covered under Automobility have already been discussed. Topics iii and iv will be discussed in this section as part of the scenario for Vancouver c. 2051.

Global Trends in Urban Design

The discourse surrounding the automobile has changed radically in recent decades. The unmitigated expansion of automobility that was encouraged throughout the 20th century is now being examined more critically as cities and policy makers seek to address the challenges they face relating to environmental degradation, air quality, noise pollution, consumption, congestion, urbanization, social inequality and land-use. Placing limits on the movement of automobiles is increasingly becoming part of the way these challenges are addressed. Subsequent and concurrent steps involve reimagining auto-space as public space and investing in public and active transit infrastructure. This shift away from the automobile creates a new focus that places people at the center of transportation policy and a new vision for the city.

The presence of the automobile within cities is being limited with a minimum aim to decrease air pollution and traffic congestion levels, foremost targeting older, polluting vehicles with diesel engines. In Frankfurt and Berlin, vehicles with diesel engines produced in 2015 or earlier have been banned from the city (Reuters 2018). Similar action has been taken in Paris, which has banned diesel engine vehicles produced before the year 2000 from the metropolitan area (Bulman 2017). This is in addition other restrictions limiting the use of vehicles produced in 1997 or earlier to weekends and after 8pm on weekdays (O'Sullivan 2018). Since 2008 , the central London has charged drivers of vehicles that do no meet low emissions vehicle standards. The tightening of emissions controls is part of a larger plan to eventually ban the sale of fossil fuel powered vehicles. Cities across the world have signed the C40 Fossil Fuel Free Streets Declaration. With signing, signatories agree to two major commitments, 1) procure only zero-emissions buses as of 2025 and 2) ensure that a major area of the city is zero emissions by 2030. At time of writing, the declaration has been signed by 28 cities, among them Los Angeles, Mexico City, Rome, Santiago, Seattle, Seoul, Tokyo and Vancouver.

A higher level of action seeks to address issues relating to noise pollution, consumption, social inequality and dated land-use practices by simultaneously dis-incentivizing private automobile use and investing in public and active transit infrastructure as well as pedestrianizing areas of the city or strictly limiting the use of automobiles in certain districts. In Mexico city for instance, cars have been banned from many plazas and major streets within the Centro district (Garfield 2018); Oslo has banned automobile parking in the central core (Garfield 2018); Paris has pedestrianized the banks of the Seine River and plans to pedestrianize the entire city centre, Rome has banned cars from Via Urbana with plans to extend the ban further, and Quito has plans for a car-free core (Garfield 2018). As the same time, all signatories plan to expand their cycling networks, introduce new public transit lines, and redesign areas of the city so as to prioritize pedestrians and non-car users.

The sum of this information suggests that cities are moving away from automobile-centric design and policy in favour of people-centric design and policy. This involves investment in public and active transit in addition to limiting the free movement of automobiles in the city through low emissions zones and pedestrianized areas. This is especially true of those cities that adopted automobility early on in the 20th century and allowed the system to mature. Now somewhat disenchanted with the collective immobility that has arisen, cities are looking to undo what was previously encouraged.

Vancouver

Population Profile

Vancouver is the most populous city in the province of British Columbia and the third largest metropolitan area in Canada. According to the 2016 census, the population of the Vancouver census metropolitan area was reported as more than 2.46 million people. Of which, approximately 631 000 people live in the City of Vancouver, and 100 000 of which live on the downtown peninsula (Statistics Canada 2019).

Vancouver's population is growing. Since 2011, the City of Vancouver has grown from 603 000 to the aforementioned 631 000 people, representing a 4.6% increase in population according to Statistics Canada (2019). Extrapolating this increase to the year 2050, it is possible that the population could swell to more than 860 000 people. This increase represents 20% of the additional 1.1 million people that are expected to inhabit the Vancouver metro area by the year 2050 (MetroVancouver, 2016).

Transit Profile

According to data collected by the City of Vancouver in 2011, the number of jobs located downtown is increasing. Compared to 1996, the number of people employed by downtown businesses increased by 26%, totaling more than 170 000 (Brown 2012, 6). Likewise, the number of people living downtown increased by 75% during the same period – recorded as 100 000 in 2011 (Brown 2012, 6). Despite this growth, the number of vehicles entering the downtown peninsula decreased from 210 000 to 175 000 (Brown 2012, 6).

This change is at least in part due to the city's mandate to decrease automobile dependence, which has been achieved by improving and expanding public transit, cycling and walking networks. In 2016 50% of trips in the City of Vancouver were made by active transit – 16% by public transit, 27% by walking and 7% by bicycle (City of Vancouver 2016, 4). By 2040, the city has set the ambitious goal of increasing this figure to 67%, meaning that even as the city's population grows, the number of trips made by automobile remains roughly the same while the overall proportion decreases. In order to achieve this, the city will have to continue expanding and improving its active transit infrastructure while reducing automobile dependence.

Vancouver's Goals

The City has identified a series challenges associated with continued automobile reliance that need to be addressed if Vancouver is to remain prosperous as it grows. The first set of issues relate to how space is used and allocated (City of Vancouver 2012). The downtown core of Vancouver is growing with respect to the number of people living in the area as well as those working at downtown businesses. This growth in turn puts pressure on the existing network of streets and generates need for public space. Due to the fact that the core is already highly developed, opportunities for expanding the road network are limited and efforts must therefore be concentrated on improving the efficiency of the existing infrastructure. It is proposed by the City that space presently reserved for motorists and parking be re-allocated for more space-efficient modes of locomotion, such as cycling, walking, and public transit. For example, a single lane, 3 meters in width, has the capacity to move 700-

1100 private vehicles per hour, 2000-3000 cyclists per hour, or 5000-6500 pedestrians per hour (Bracewell 2018, 28). If that lane is designated for public transit such as a city bus or light rail passenger train, it can move 2000-4000 people or 16 000-24 000 people per hour, respectively (Bracewell 2018, 28). It can be seen that, assuming single occupancy, private vehicles are the least efficient means of transporting people by this metric. However, the efficiency of private vehicles could be improved if the way they are used is altered – that is, if car pooling were to become common practice.

The second set of issues relate to the social and demographic challenges the city faces. The sedentary lifestyle automobile dependent transportation systems encourage has systemic costs related to health and health care. Lack of exercise strongly correlates with the prevalence of obesity, heart disease and depression. In 2001, it was estimated that 5.3 billion dollars in Canadian healthcare costs could be directly or indirectly attributed to physical inactivity (CIHI 2016). According to the Canadian Institute for Health Information, 2016 national level healthcare spending for the 27.8 million Canadians aged 0 - 59 totaled approximately 2.54 billion dollars. For the 8.2 million Canadians aged 60+, healthcare spending totaled more than 15.1 billion. This poses a challenge to the city of Vancouver as it is projected that by 2050, more than 30% of the city's population will be over age 60. So while healthcare spending is of federal jurisdiction, the construction and maintenance of healthcare facilities, including hospitals, is very much a municipal concern. Moreover, cities, as the site of daily life, are largely responsible for facilitating the healthy lifestyle that will reduce healthcare costs as people age. The city of Vancouver views inactivity facilitated by automobile dependence as a factor contributing to poor physical and mental health. Therefore by making walking, cycling, and public transit convenient and comfortable alternatives to driving, the city hopes to reduce the long term costs associated with a lifetime of inactivity.

The final set of issues are largely economic, relating to the city's high cost of living. Vancouver is consistently ranked among the least affordable cities in the world to buy a home. Further, the cost of fuel is typically among the highest in Canada. As a way of offsetting these costs, the city, again, views low cost transportation options as a way of offsetting the high cost of housing and fuel.

Autonomous Vehicles

Between 2020 and 2060, autonomous driving will advance from the initial stages of research and development to near total market ubiquity (Bracewell 2018, 6). In a study conducted by the Victoria Transport Policy Institute, it was estimated that if the implementation of autonomous vehicle technology follows the developmental timeline of other vehicle technologies, it will take one to three decades for the AV technology to dominate vehicle travel. As AV technology becomes common place, a supporting infrastructure will also be implemented, and cities will modify their land use strategies in order to capitalize on the capabilities of autonomous vehicles.

Vancouver has already begun to imagine how they will adapt their street network to autonomous vehicles. Its preliminary plans include: reducing the width and number of vehicle travel lanes, reducing the number of on-street parking spots while creating more drop-off/pick-up zones, allocating more space to civic priorities, and implementing 'smart city' infrastructure (Bracewell 2018, 35). There are also initial plans in place to re-imagine parking structures as a shared resource among commercial and residential users. This strategy would reduce or eliminate the responsibility placed on property developers to incorporate parking into buildings.

The Scenario

Automobility c.2051

The scenario for Automobility proposes that the system is perpetuated and reinforced by streamlining the 'ownership' experience, reducing production, operational and design costs, promoting new ways of using automobiles, and integrating into economic channels.

The automobile of 2050 is fully autonomous and integrated into the three internets – transportation, energy and communication. It is capable of moving from task to task and managing its energy supply.

The automobile industry is split into two factions, the first (automobile I) continues to design and sell the automobile as a symbol of status and communicator of values; the second (automobile II) is integrated within the sharing economy and provides mobility as a service. In both cases, access to an automobile is obtained through a subscription plan that integrates insurance and maintenance costs. In the case of automobile I, it is still possible to privately own an auto – but at a cost.

The subscription-based model streamlines and simplifies the 'purchasing' and 'ownership' experience. In combination with AV technology, subscribing to a package has made it possible to completely eliminate the dealership model.

Instead, potential subscribers visit corporate showrooms to evaluate package options and test floor models. The process resembles that of a mobile-phone upgrade. A range of subscription packages are offered depending on how much the auto will be used and the degree to which it will be shared. It is possible to privately subscribe – but at a cost.

The experience of subscribing to an autonomous auto is hassle free. Integrating the cost of maintenance into the subscription makes it possible for autonomous automobiles to ensure they are always in safe operating condition. Subscribers never have to schedule maintenance or wait for their vehicle while it is being serviced– the auto will drive itself to the shop for both scheduled and unscheduled maintenance. Because autos are shared, they function as a network to manage demand– no single auto belongs to a single subscriber (unless the upgraded package is purchased), therefore ensuring that access to an automobile is unlimited and uninterrupted. If the upgraded package is purchased, then access to the network ensures an automobile is available in the event the subscriber's personal auto is unavailable.

The transition from private ownership to sharing allows automakers to effectively sell the use of a single vehicle to multiple users – thereby reducing total production while increasing revenue. Reduced production demand is handled at smaller, localized factories that employ robots and 3D printers to fabricate and assemble the autos and auto parts. The production of autos is managed according to demand, and redundant, overproduction is eliminated – autos are essentially made to order. Upon completion, finished autos enter service directly, eliminating the cost of transportation from site of assembly to point of sale.

In the subscription based model, the automaker maintains ownership of the automobile, guaranteeing their control over the vehicle's life-cycle. At the end of an auto's useful life, it returns to the automaker to be disassembled and recycled instead of being resold on the used market. The used automobile market no longer exists – except among elite clients. When an auto leaves to be disassembled for recycling, it has no effect on the subscriber – another auto will take its place within the network.

The cost of designing and producing automobiles is reduced through simplification and modularity. A single scalable platform is shared across models and options for power units (combination of motor and battery) are limited. Vehicle optional extras are very few if not eliminated completely – the majority of automobiles are built to a 'one size fits all' philosophy in order to better suit sharing and subscription. Research and development costs are invested in that which buyers can see and touch as well as the latest technology. Vehicles are tuned to be ridden-in rather than driven.

The autonomous automobile provides a more comfortable alternative to domestic flights, rail and coach bus. In combination with specialized highway infrastructure, autonomous automobiles travel at high speeds between cities at any time of day. Passengers are free to sleep, work, read, play games, etc... as they travel for business or leisure.

AV technology allows the automobile to be used by people with varying degrees of mobility, including children and the elderly. Twentieth century automobility required a high degree of mobility, driver training and a license. The automobile of the 21st century can be used by virtually anyone.

The autonomous automobile is a new interface and gatekeeper. It eliminates the driver in delivery, public transit and taxi scenarios. It replaces the human-human interactions of the 20th century with human-automobile interactions. This reduces operating costs within relevant industries.

The autonomous automobile is integrated into the economy in new ways, resulting in mutualistic relations. The first is the renewable energy sector. This relationship is analogous to the co-dependence that evolved between the oil and gas industry and the automobile in the 20th century. Electric automobiles consume energy generated from renewable sources. Consumption by electric vehicles supports and reinforces the renewable energy sector, while automobiles are dependent on the energy it produces.

Autonomous automobiles require internet integration to realize their potential. Telecommunications firms will be responsible for providing service to every facet of transportation infrastructure in order to ensure the proper function of the automobile. Similarly, cyber security firms are among the greatest benefactors of complete and total internet integration.

Autonomous vehicles present new opportunities for electronics firms and media companies. In-vehicle entertainment and interfaces play a major role in the design of autonomous vehicles. Ergonomics are no longer designed around driving, but rather working and socializing. Novel ways of engaging the outside world from inside the automobile are implemented.

Vancouver c. 2051

Population growth for the Vancouver metro area has exceeded the 3.5 million people that was predicted in 2016. In 2051, the population of the metro area's primary municipalities has surpassed 3.6 million (see table Metro Vancouver Population) and the largest, most populace municipality is now Surrey with over 1 million people. Low land values relative to the core have fueled the growth and development of Vancouver's suburbs – Burnaby, New Westminster, Richmond and Surrey. The economic activity of these cities nearly rivals that of Vancouver. However, Vancouver's downtown is still the center culture, entertainment and commercial activity.

Vancouver's downtown peninsula, an area 5.7 km^2 , is the densest part of the city with more than 31 000 inhabitants per km^2 (see table Metro Vancouver Population)– approaching that of areas of Hong Kong. Growth in this part of the city as well as that of the metro area exerts considerable pressure on the available public space and amenities. Downtown's transient population of workers, tourists and visitors triples the peninsula's resident population every day.

Despite population growth, the number of automobile's entering downtown everyday has not significantly increased relative to 2016 – approximately 180 000 compared with 175 000. This is due in large part to, i) the considerable investment into public and active transit infrastructure since 2020 and ii) the adoption of autonomous, electric vehicles, in combination with the growth of the sharing economy. Many suburbanites travelling to the core for work have adopted a multi-modal approach to commuting by using an autonomous vehicle or bicycle to travel to a nearby skytrain station, then continuing on to the core.

The sharing economy has made it possible to maintain mobility with fewer automobiles. Relative to 2016, there are 70% fewer vehicles registered in the metro area (approximately 1.16 million vs. 368 thousand). The vehicles that are in service, however, spend very little time parked. These vehicles are all autonomous and move from task to task, stopping only to charge or for maintenance. As a result, overall traffic has not necessarily decreased, even if it flows more efficiently. Furthermore, there are often vehicles on the road that are empty as they move between tasks or travel to distant charging stations that were built on the edge of the city.

The changes to the automobility can be felt in the city. Many residential underground parkades have not been retrofit with vehicle charging and as a result sit mostly empty. Roads originally designed to accommodate multiple lanes of traffic and parked automobiles now feel too wide. Moreover, many of the structures that were built for parking now need to be redeveloped.

In addition to disused space and empty vehicles roving the streets, other issues have arisen. Autonomous vehicles have made it so that a long commute represents less of a barrier to living on the city edge. As a result, urban sprawl continues to consume prime agricultural lands in the British Columbia Lower Mainland Region. This trend is compounded by the high cost of housing in Vancouver and general lack of housing stock - rapid growth in the region has been difficult to keep up with. This need for housing in the city, particularly within the core where speculative building practices are pervasive, has been developed at the expense of Vancouver's inner-city industry.

Municipality	Area (km^2)	2011 Population	2016 Population	2016 Growth	2016 Density/km^2	2051 Population	2051 Density/km^2
	Metro Vancouver Population					2051 Estimates**	
Peninsula*	**5.74**	**99,230**	**106,590**	**7.90%**	**17,422**	**181,496**	**31,619**
Vancouver	115	603,502	631,486	4.64%	5,491	867,457	7,543
Surrey	316	468,251	517,887	10.60%	1,639	1,048,385	3,318
Burnaby	97	223,218	232,755	4.27%	2,400	311,899	3,215
Richmond	129	190,473	198,309	4.11%	1,537	262,899	2,038
Coquitlam	122	126,804	139,284	9.84%	1,142	268,674	2,202
Langley	308	104,177	117,285	12.58%	381	268,826	873
Delta	184	99,863	102,238	2.38%	556	120,536	655
North Vancouver	161	84,412	85,935	1.80%	534	97,365	605
Maple Ridge	267	76,052	82,256	8.16%	308	142,441	533
New Westminster	16	65,976	70,996	7.61%	4,437	118,632	7,415
Port Coquitlam	29	55,958	58,612	4.74%	2,021	81,054	2,795
West Vancouver	87	42,694	42,473	-0.52%	488	40,951	471
Total		2,141,380	2,279,516			3,629,120	

* Peninsula is combination of West End and Downtown districts

** 2051 estimates are based on the hypothetical scenario that growth is constant and equal to growth from 2011-2016

Population estimates for metro Vancouver by municipality based on constant growth. (Data from Statistics Canada Census Profile, 2011 Census, Vancouver; Statistics Canada Census Profile, 2016 Census, Vancouver; City of Vancouver Downtown Census Profile 2017a; City of Vancouver West End Census Profile 2017b)

Estimated Number of Registered Vehicles

City	Population*	People/Car	Cars registered**	Population	People/Car***	Cars Registered
	2016 Estimates			2051 Estimates		
Vancouver	631,486	2.3	270,000	867,457	11.7	74,178
Surrey	517,887	2.1	250,000	1,048,385	10.4	101,218
Burnaby	232,755	2.1	110,000	311,899	10.6	29,481
Richmond	198,309	1.8	110,000	262,899	9.0	29,166
Coquitlam	139,284	2.0	71,000	268,674	9.8	27,391
Langley	117,285	1.5	79,000	268,826	7.4	36,215
Delta	102,238	1.8	56,000	120,536	9.1	13,205
North Vancouver	85,935	1.1	77,000	97,365	5.6	17,448
Maple Ridge	82,256	1.9	44,000	142,441	9.3	15,239
New Westminster	70,996	2.2	33,000	118,632	10.8	11,028
Port Coquitlam	58,612	1.8	32,000	81,054	9.2	8,851
West Vancouver	42,473	1.6	27,000	40,951	7.9	5,206
Total	2,279,516		1,159,000	3,629,120		368,625

* Statistics Canada, 2016 Census

** ICBC, Quick Statistics for the Media Manual, 2018

*** The Metro Vancouver Car Share Study Technical Report

For every car shared, between 5 and 11 cars are removed from the road. Conservative estimate was used.

Estimated number of registered vehicles in 2051. (Data from Statistics Canada Census Profile, 2011 Census, Vancouver; Statistics Canada Census Profile, 2016 Census, Vancouver; City of Vancouver Downtown Census Profile 2017a; City of Vancouver West End Census Profile 2017b)

CHAPTER 4: SITING

A New Urban System

Design Parameters for a New Urban System

The automobile of c. 2051 is very different from the automobile of the 20th century. It is autonomous, electric, shared, and integrated into the internet. These new capabilities render much of the existing infrastructure inefficient, obsolete or functionally inadequate. Therefore it is possible to update or reimagine the existing system in order to fulfill the automobile's potential. This thesis assumes the stance that this potential is not only worth exploiting but that doing so creatively and critically could result in new, more spatially and functionally efficient ways of transporting goods and people urban in environments.

Automobility is an autopoietic system that will continue to evolve and adapt at a rate that outpaces the typical lifespan of a building or infrastructure system. It is likely that the automobile of 2020 will be obsolete in 2050, and the automobile of 2050 will be practically obsolete in 2080. Furthermore, it is also possible that completely different transportation, communication and energy technologies will emerge and trigger the transition to a new economic system, subsequently triggering the development of a new infrastructure system. Therefore designing for today rather than a figurative tomorrow is likely to result in stranded assets as well as wasted time, money and resources.

The metro Vancouver area will grow rapidly between 2020 and 2050 in terms of population and development. While the city is preparing for this growth, it stands that it will strain the city's existing systems - transportation, public/civic, agricultural, distribution, etc... if they are not sufficiently adapted. Vancouver, and other cities like it, seeks to address this issue in part by reducing the pressure automobility places on its urban systems. City's are doing this through two concurrent processes, the first by moving away from automobile-centric urban design and transportation policy. This involves taking action to make travel by private automobiles less convenient, such as pedestrianizing streets or entire areas of the city, implementing low or zero emissions zones, charging congestion fees, and reallocating space to other road users. These actions are complimented by the second process, which involves effort to make public and active transit more convenient and comfortable. This involves investing in infrastructure to support low-impact modes of transportation such as walking and cycling while also allocating more space and resources to public transit.

This thesis suggests that updating and adapting existing infrastructure to be more functionally and spatially efficient, creating new sets of Infrastructural and architectural components and systems that are adaptable, convenient and easy to use as well as comfortable can be achieved in the following ways:

i) Pedestrianization of large parts of the city, limiting automobile traffic to the minimum necessary, and prioritizing the development of active transit infrastructure, rendering the automobile less convenient thereby discouraging its use. Further, it will make available space within the city presently reserved for the automobile for other *uses*, such as water capturing and filtration, recreation, social interaction, sports, or energy production; *users*, such as children, the elderly, non-car owners, or the differently-abled; and *modalities* such as bicycles, skateboards, scooters and other yet-to-be-invented devices.

ii) Introduction of an intelligent mediating system that will work to maintain the pedestrian zone while also meeting the needs of the city in regards to the transportation of goods and people. By Integrating the system into the transportation and communication internets, urban-scale, real-time and demand-based resource management can be achieved. The intelligent mediating system is comprised of a physical and digital infrastructure. Via the communication and transportation internets, the system coordinates and manages the flow of vehicles transporting goods and people. A general physical infrastructure is responsible for, and capable of handling inter-transit activities, examples of which include the storage, charging, and deployment of vehicles or the sorting and storage of goods. The combined digital and physical infrastructure has been dubbed the Hive.

iii) Introduction of the Hive, a network comprised of a series of strategically located hubs (also referred to as hives) is established . The location and programmatic function of hives is determined through a method that will be referred to as a *MARC Analysis*. A MARC Analysis is a means of evaluating a site's suitability to a hive. Suitable sites provide opportunities for a hive to Mediate between opposing forces, Assimilate existing programs, Respond to the surrounding context and Connect modalities and systems (MARC). A MARC analysis of the existing urban system at various scales will reveal potential sites where the introduction of a hive can create an influential locus of density.

Mediation is an ongoing process of adaptation to technological, social and economic change that involves multi-scalar resource management, programmatic shift, expansion, contraction and additive retrofit. This thesis suggests that this is possible through internet integration, a series of modular unit types and automated construction methods.

Locating the Hive

The Hive is located according to its potential to Mediate, Assimilate, Respond and Connect (MARC). Examining the metropolitan area of Vancouver (see Map of Metro Vancouver), commercial centers are identified as points of convergence within the urban system. The high number of people that travel to and from commercial centers for work, recreation and shopping each day translates to programmatic density and system convergence, thus resulting in opportunities for the Hive to MARC. Let us consider the downtown Vancouver peninsula as a test site for a prototype Hive system.

HIVE NETWORK

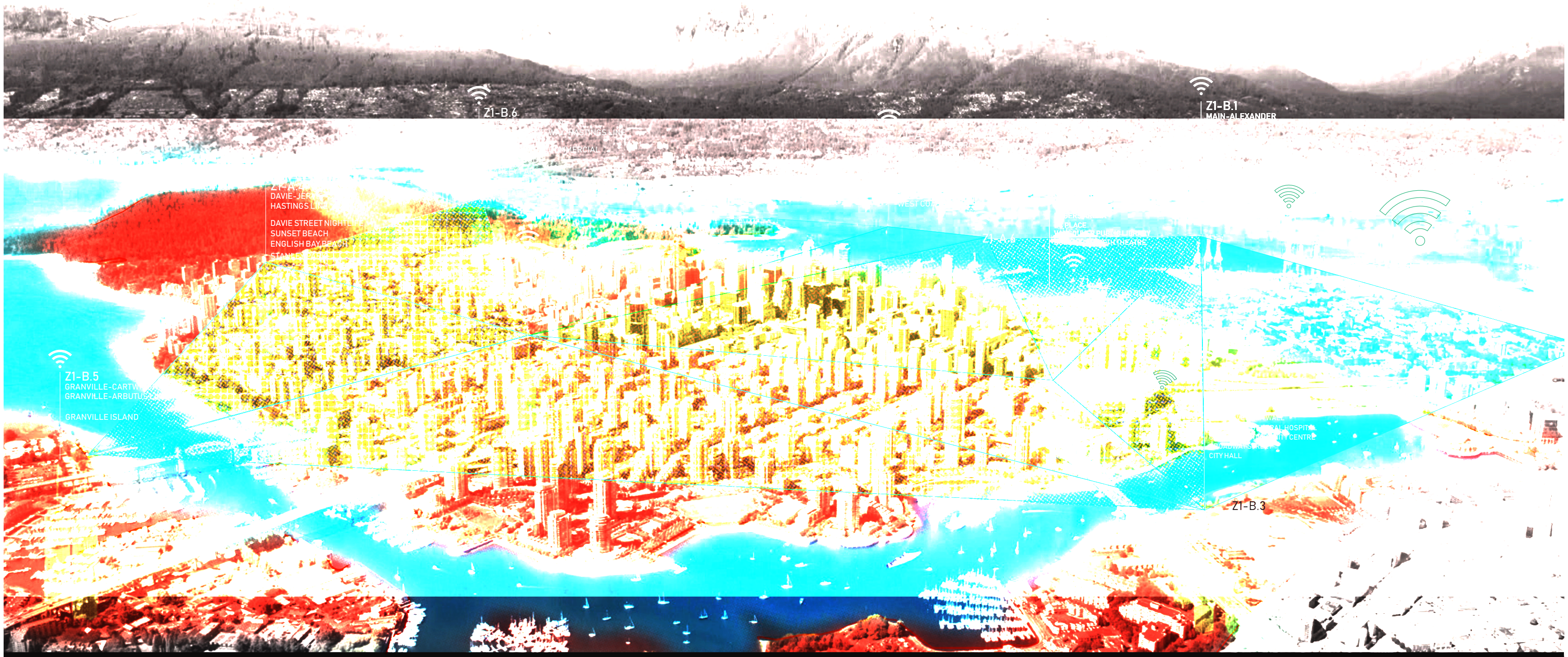
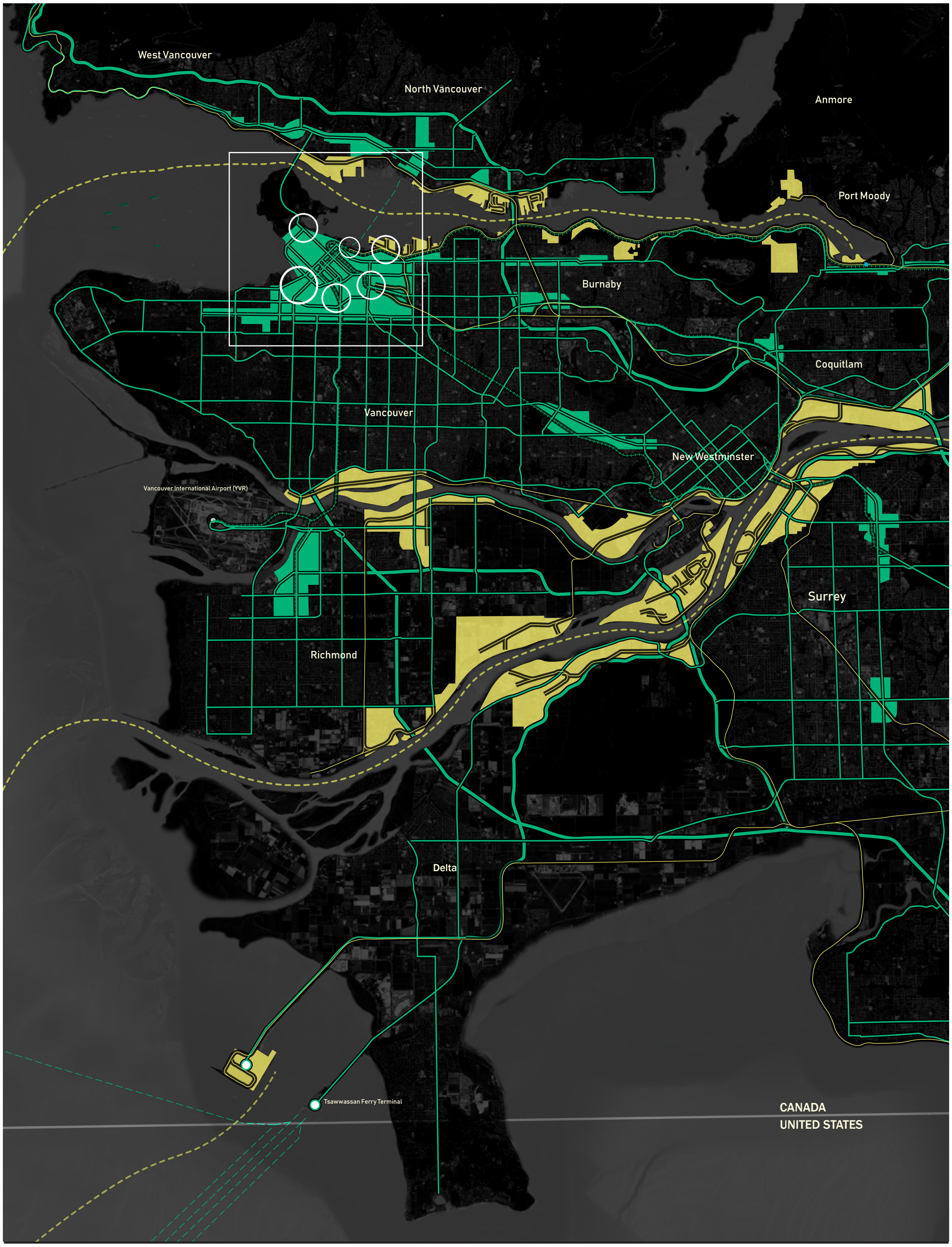
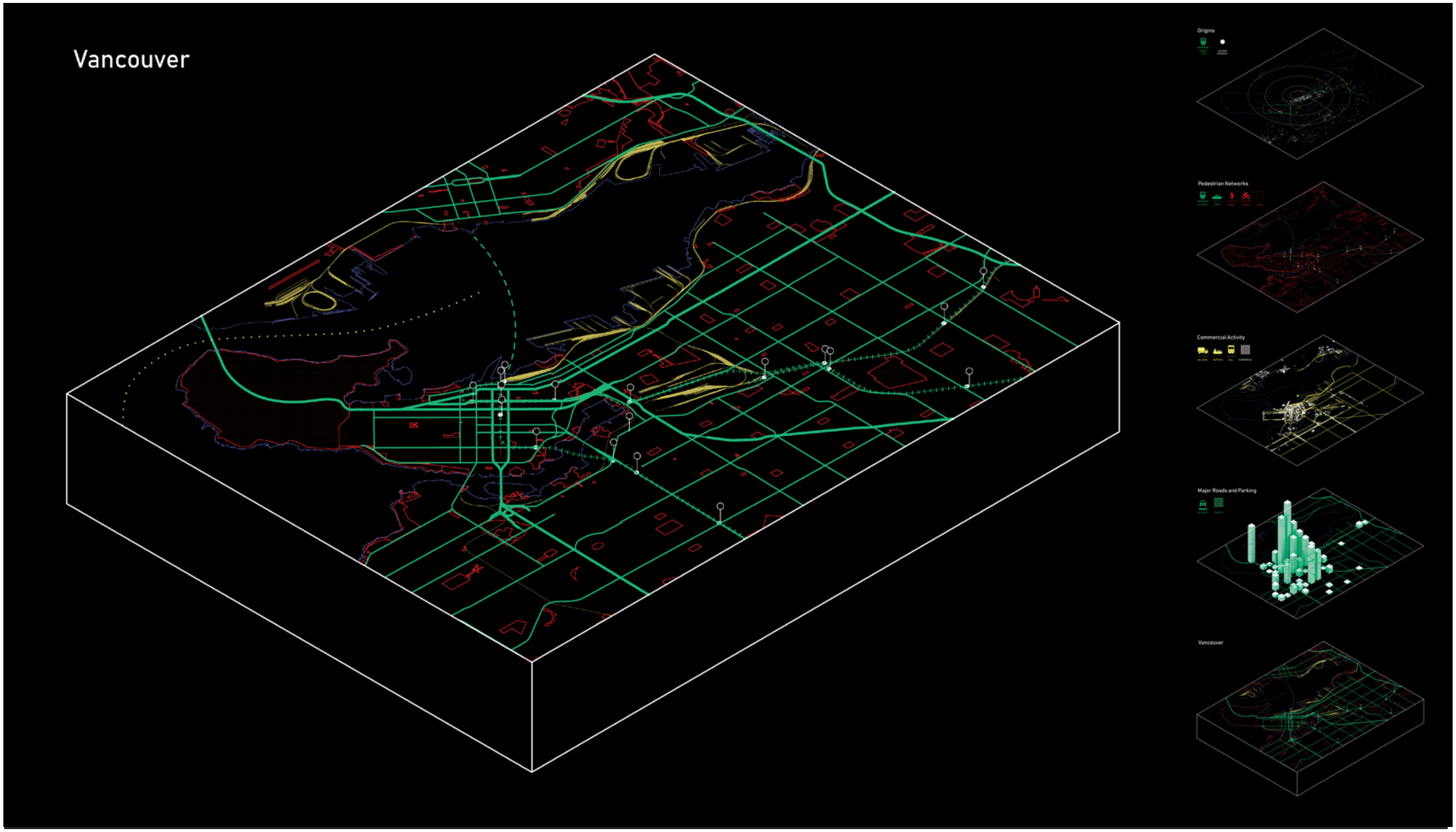


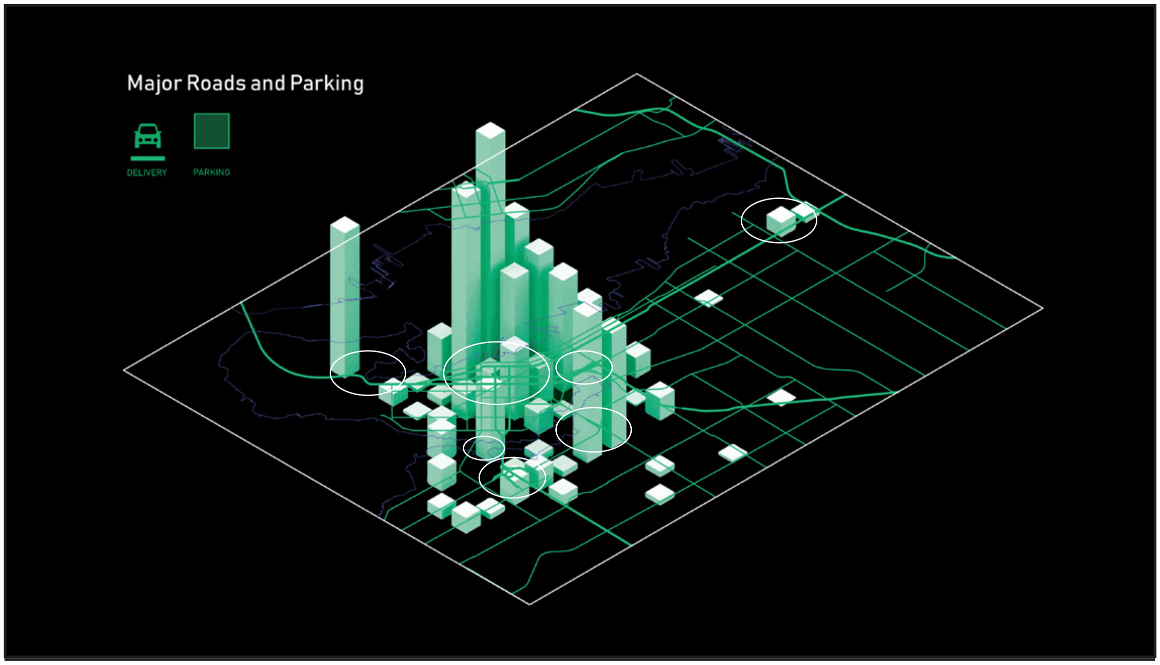
Illustration of proposed Hive network for Vancouver's downtown peninsula (image adapted from Port Metro Vancouver)



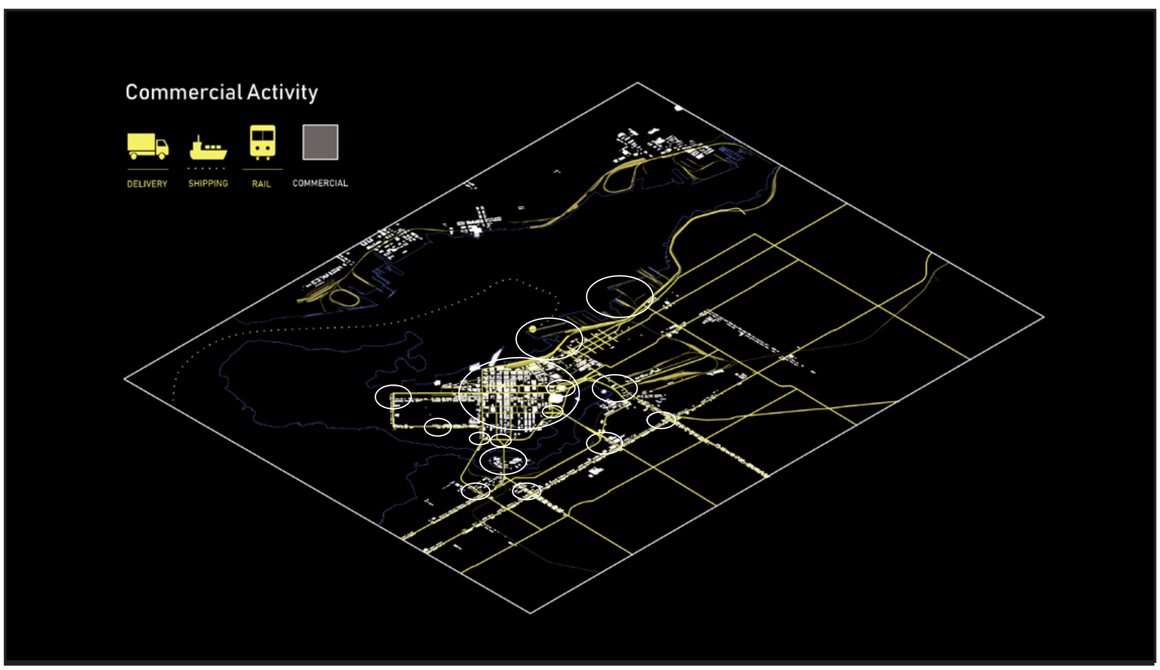
Map of Metro Vancouver: commercial centres (green) , industrial zones (yellow), major points of entry, major public and industrial routes. Commercial centers and industrial zones are major destinations for work and shipments. Both provide unique opportunities for the introduction of a Hive network; satellite image from Google Earth.



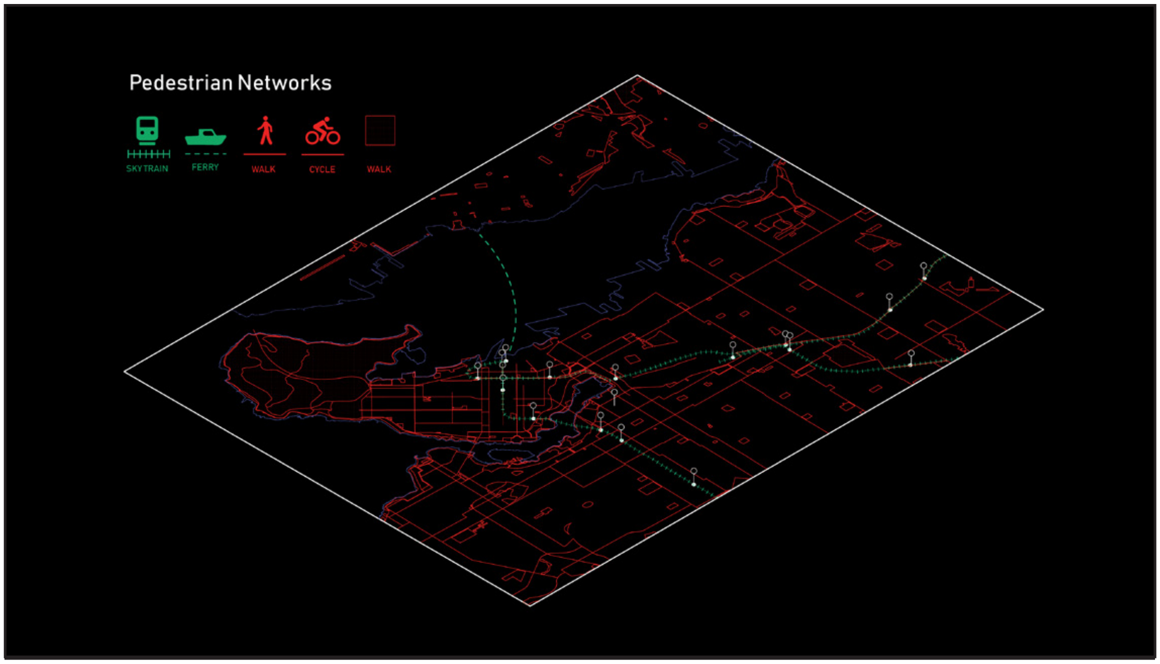
Isometric Drawing of Central Vancouver depicting major transportation routes and parks; data collected from the (GIS data from the City of Vancouver Open Catalogue 2019a; 2019h; 2019i; 2019j; 2019k)



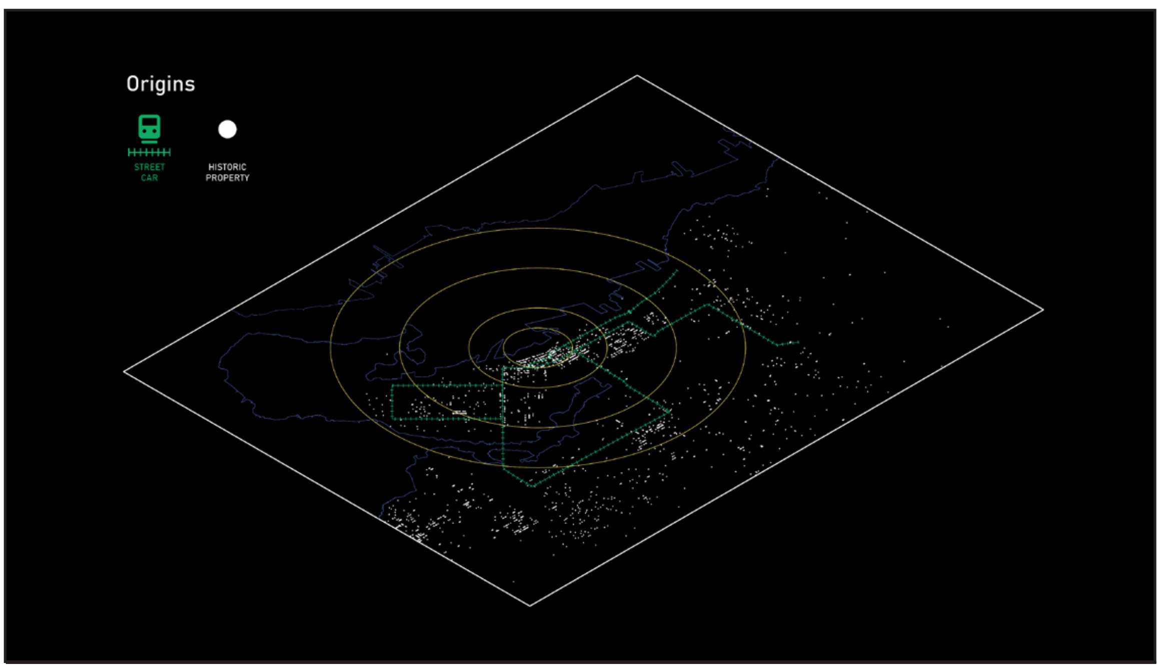
Major roads and paid parking. The assimilation of inter-transit activities (i.e. parking and charging) is a primary determinant of hive siting. Gateways and bottlenecks are points of convergence for people and goods leaving or entering the downtown peninsula. Such locations are a natural point to leave the car and switch modality. (GIS data from the City of Vancouver Open Catalogue 2019a; 2019k ; parking data collected from Impark, Easypark)



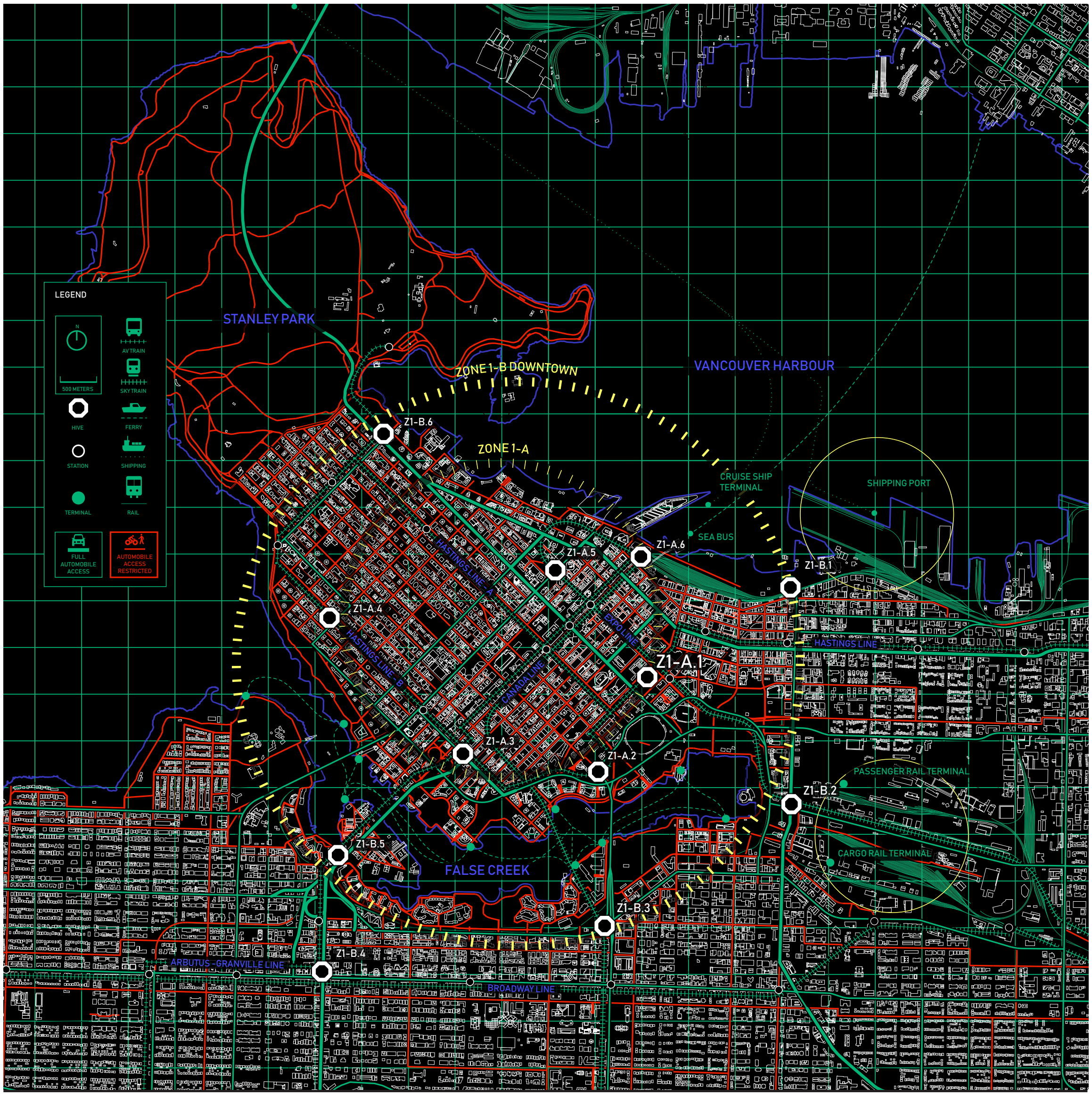
Commercial activity - commercial streets, truck routes, light and heavy rail. Shipping and rail terminals connect to road based routes for distribution. Points of convergence such as intersections, gateways and bottle necks are opportunities to improve connectivity and increase programmatic density by responding to unique local context. (GIS data from the City of Vancouver Open Catalogue 2019a; 2019i; 2019k)



Pedestrian Networks - Recreational areas provide a unique opportunity to respond to and complement. Areas where industrial, recreational, commercial and residential activities converge are opportunities to assimilate, respond and connect. (GIS data from the City of Vancouver Open Catalogue 2019b; 2019e; 2019g; 2019j; 2019k)



Origins - Areas with historic character provide a unique context to respond to. Hives can concentrate the activities that detract from the experience of these neighbourhoods and improve connectivity to them. (GIS data from the City of Vancouver Open Catalogue 2019d; 2019f; 2019k)



Proposed Hive Network for Vancouver's downtown peninsula. Hives are primarily located at gateways and points of entry to the downtown peninsula allowing them to manage entry to the pedestrian zone while establishing a link between the city's downtown industrial programs and the public realm. (GIS data from the City of Vancouver Open Catalogue)

The Hive

The organization of the Vancouver Hive locations was determined by three factors, i) the nature and logical limits of the pedestrianized area, this includes identifying which roads could be considered essential to the function of the city, ii) the introduction of additional permanent transit lines, and iii) the siting of hives through a study of existing parking infrastructure and overlay of a MARC analysis.

The prototype Hive network for Vancouver's core is organized as an outer ring and an inner ring. Hives along the outer ring are located at core's various gateways and mark the transition from auto-space to pedestrianized city center. Essential routes through and along the circumference of the pedestrian zone are preserved for the general movement of private autos, deliveries and through-traffic. Automobile traffic is limited to designated routes by geo-fencing. However, access to the geo-fenced area can be obtained for the purposes of delivery or moving.

When arriving to the city center by automobile, the outer ring of hives is the first and suggested point of switching to public or active transit. If necessary, private autonomous vehicles may be stored and charged at these points or they may continue to another destination. The outer ring is responsible for connecting the sea (Z1-B.1) and rail (Z1-B.2) cargo terminals to the city's other systems and assimilating the distribution function of these sites.

The inner ring of hives serve as major transit stations, connecting transit lines to one another as well as other modalities. Hives within the inner ring are proximal to major recreational, commercial and civic sites. Hive Z1-A.4, for example, is a landmark that connects Davie Village to English Bay and Sunset Beach.

Pedestrian Zone

The designated pedestrian zone is a geo-fenced area that includes the entirety of Vancouver's downtown peninsula from Stanley Park to Main Street as well as the area south of False Creek that includes Granville Island, Olympic Village, numerous parks and the Vancouver Sea Wall. Access to the pedestrian zone via automobile can be obtained in the event of emergencies or for the purposes of deliveries, moving or arriving home late at night when safety is a concern. However, with the exception of emergencies, automobile speed is limited to 15 kph.

The pedestrian zone is serviced by automobiles via essential routes. First, a circumferential road connects the peninsula's gateways: Stanley Park, Burrard Bridge, Granville Bridge, Cambie Bridge, Main Street and Hastings Street. Burrard (north) and Thurlow (south) are maintained as a one-way north-south corridor and West Georgia is maintained as a two-way east-west corridor. This organization resembles the existing network of major roads depicted in the map of Major Roads and Parking - with a few exceptions. In some cases, a major road has been designated as a pedestrian street or transit corridor due to experiential qualities of the street that would be enhanced by eliminating automobile activity.

Transit

Two new permanent transit lines have been proposed as part of the scheme: a Granville-Arbutus Line travelling north-south from the existing Waterfront Station to Bridgeport Station and a Hastings Line travelling east-west from Highway 1/ Second Narrows Bridge to Stanley Park. The Hastings Line splits into a north A-line that travels along Robson Street and a south B-line that travels along Davie Street. The location of these lines is based on historical precedence (see the map titled Origins) and the City of Vancouver's plans for the Arbutus Greenway.

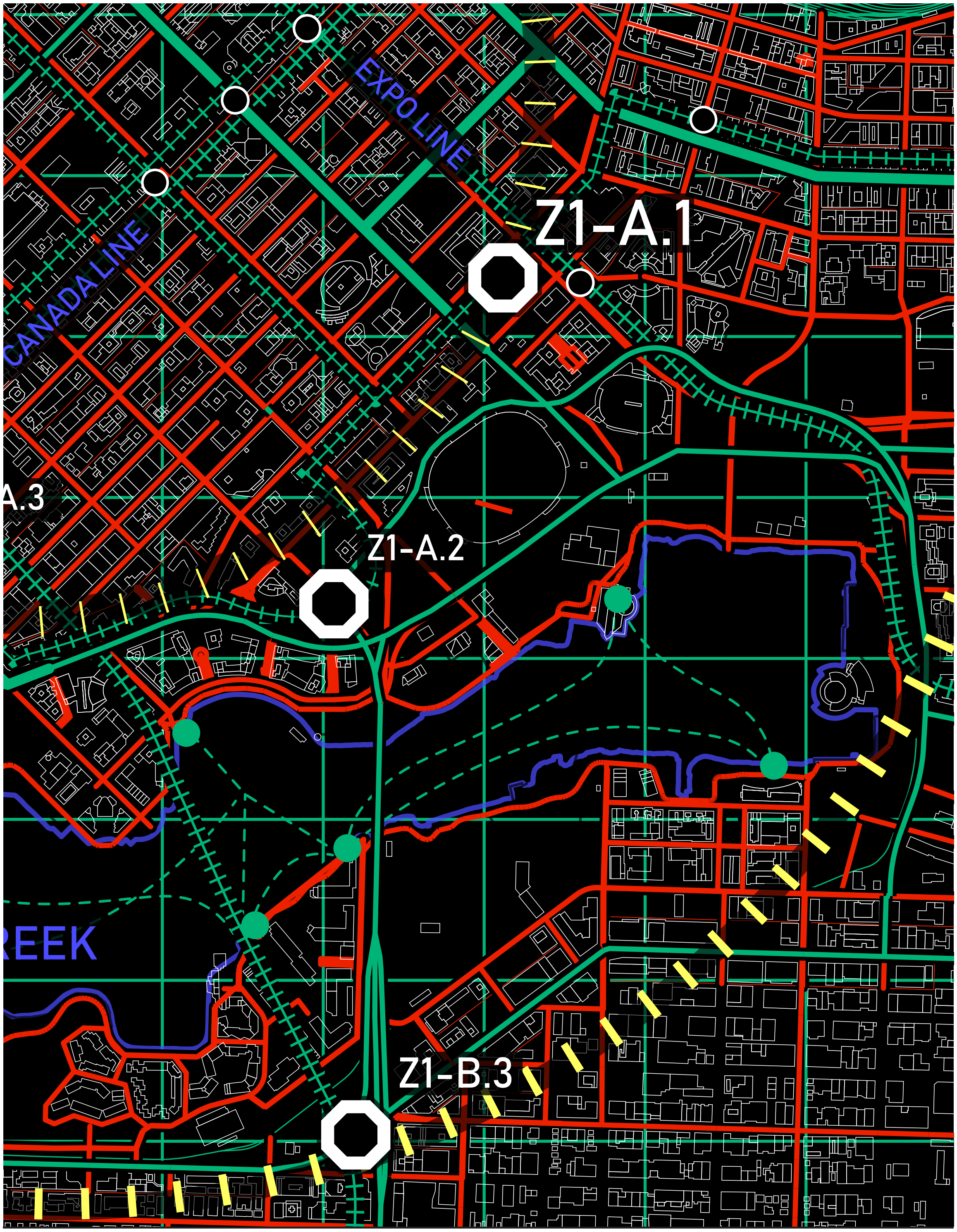
Locating Hives - MARC Analysis

The location of hives was determined through a MARC analysis of potential sites. The first step is identifying transportation and distribution nodes and gateways in order to determine how or if connectivity between modalities and systems can be increased or exploited. These sites are cross referenced with existing automobile infrastructure that can be assimilated into the hive. Activities where the automobile is integral, such as distribution and delivery may also be assimilated. The third step involved identifying points of unique contextual interest (POI) that could be enhanced or complimented by a hive. Examples of such include civic buildings, educational institutions, parks and public spaces, entertainment and performance centers, museums, etc... Sites with a high number of POI are more desirable than sites with few POI. The introduction of a hive may compliment its context through the provision of housing, performance or exhibition spaces, commercial space, a park, etc...

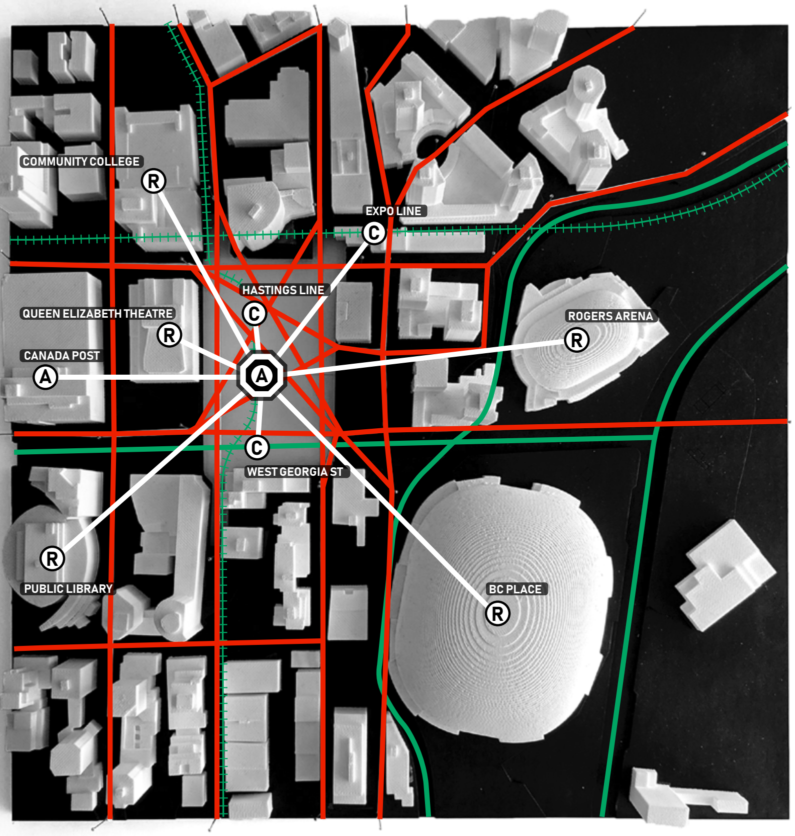
The Vancouver Hive system is organized into an outer ring and an inner ring. When arriving by automobile, hives along the outer ring represent the first and suggested point to switch from automobile to public or active transit before entering the pedestrian zone. Several outer ring hives, especially Z1-B.1 and Z1-B.2, connect and assimilate the industrial functions of the rail and sea terminals to the pedestrian city. Inner ring hives serve as major transit stations and hubs within the city.

MARC Analysis of Hive Z1-A.1

Hive Z1-A.1 assimilates the existing parking lot and farmers market as well as the neighbouring Canada Post distribution center. Z1-A.1 responds to BC Place, Rogers Arena, the public



Site of focus - Hive Z1.A1: intersection of Cambie Street and West Georgia Street. Hive Z1-A.1 manages traffic travelling along the West Georgia through-fare and connects the existing Expo Skytrain Line to the proposed Hastings Line. Z1-A.1 assumes the role of the existing farmers market, Christmas market and public space. Z1-A.1 responds to the Vancouver Central Library, Vancouver Community College, BC Place and Queen Elizabeth Theatre. (GIS data from the City of Vancouver Open Catalogue)



MARC - Hive Z1.A1: Mediate between city and automobile, Assimilate Canada Post, parking, and farmers market. Respond to Stadiums, Public Library, Community College and Queen Elizabeth Theatre. Connect Expo Line, Hastings Line, West Georgia auto thoroughfare, and pedestrian realm.

library, community college, and Queen Elizabeth Theatre. Student housing, temporary housing and hotel, rooftop park with sundeck, running track and basketball and tennis courts, green space, restaurants, grocery stores, a post office, and cafes fill commercial spaces. It connects the West Georgia St. east-west automobile corridor to the Hastings and Expo transit lines. Each hive is a combination of public and private infrastructure. Typical horizontal processes have been reorganized as vertical processes.

Illustration of Hastings Street without automobile traffic (image adapted from Angelvancouver)

CHAPTER 5: HIVE ARCHITECTURE

The framework used to determine the Hive site (MARC analysis) can also be used to design the Hive, thereby aligning its architectural expression with its function. In terms of design, MARC translates as follows:

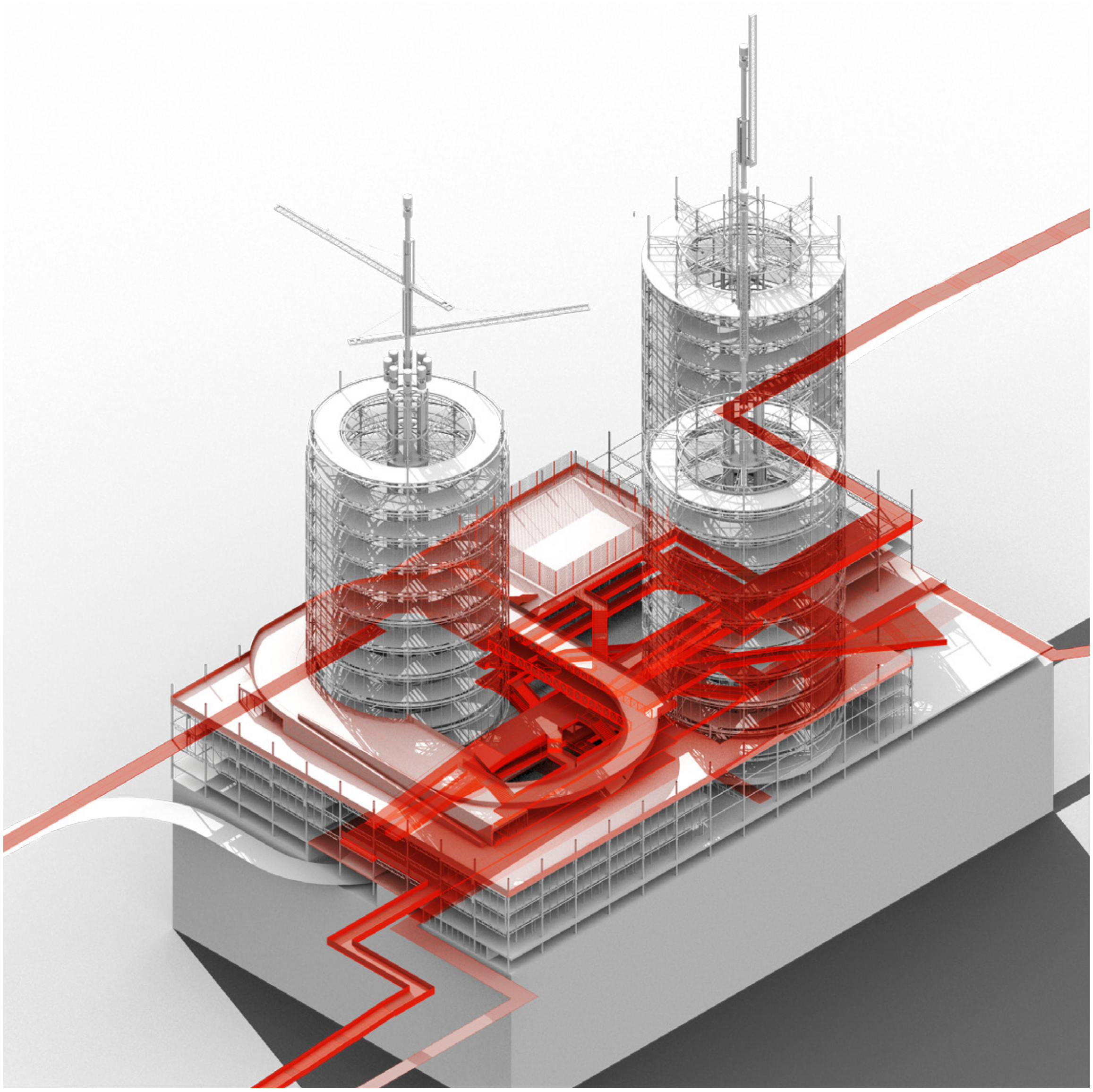
Mediation: designing for mediation involves integrating a set of mechanisms and methods of construction that allow the hive to expand, contract and adapt to evolving technological, social and economic contexts. It also involves integrating the architecture into the transportation and communication internets. Designing the hive as a mediative tool allows the City to define the role of technologies such as the automobile as they continuously evolve. Mediation refers to role of the hive as a network functioning between the city and larger global technological forces.

Assimilation: in terms of design, assimilation involves the integration of pre-existing program and reorganizing it as a vertical, spatially efficient process.

Respond: Designing the hive to respond employs the same methods and mechanisms as mediation. However, responding is a more localized process that works to enhance qualities or trends present in a neighbourhood while countering those that are undesirable.

Connect: Designing for connectivity involves connecting as many modalities as possible to create a city that is clear and easy to get around without the use of an automobile. It also involves the creation of a layered and complex public realm, blurring the line between public and private space.

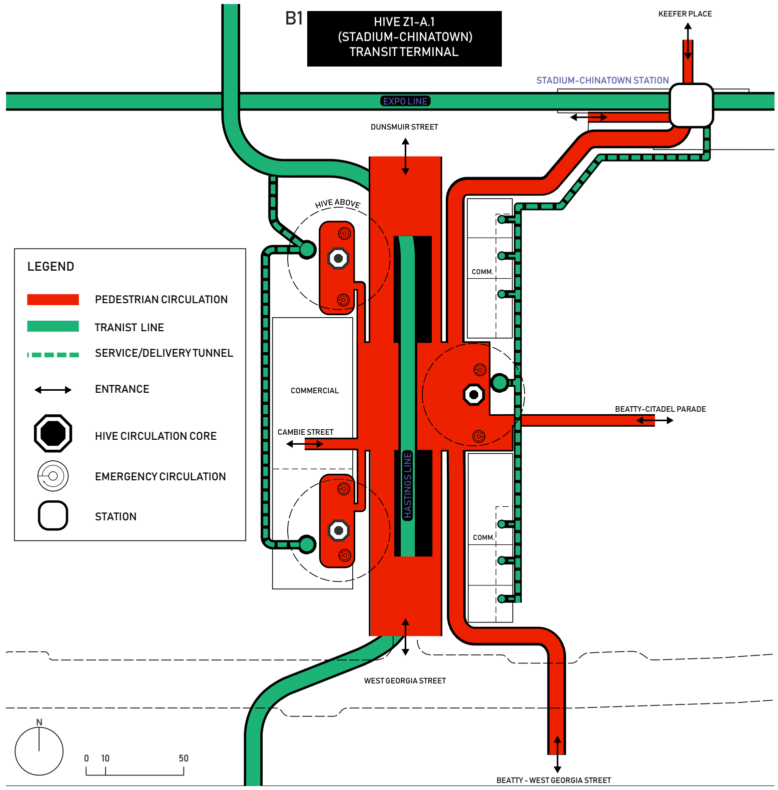
Rendering of cyclist entering the pedestrian zone via the Cambie Bridge



Isometric view of multilevel public space. A rooftop deck features a running track, basketball courts, and a south facing sundeck.

Connect

Hive Z1-A.1 connects private automobile based transit to active and public transit, making it easy to move through the city according to what makes the most sense. However, the richest experience is enjoyed by the pedestrian who is able to move through the site at multiple levels - below, at, and above the street.



Map of transit level showing connectivity between stations and various entry points

Below the Street

The city block is bisected north-south by a ramp that connects the street to the below grade Hastings Line Station. The station is lined on either side by shops, cafes and restaurants. An underground street connects the Stadium-Chinatown skytrain station to the Hastings Line station to the south side of West Georgia Street. Entrance to the upper levels of the hive is accessible by elevator.

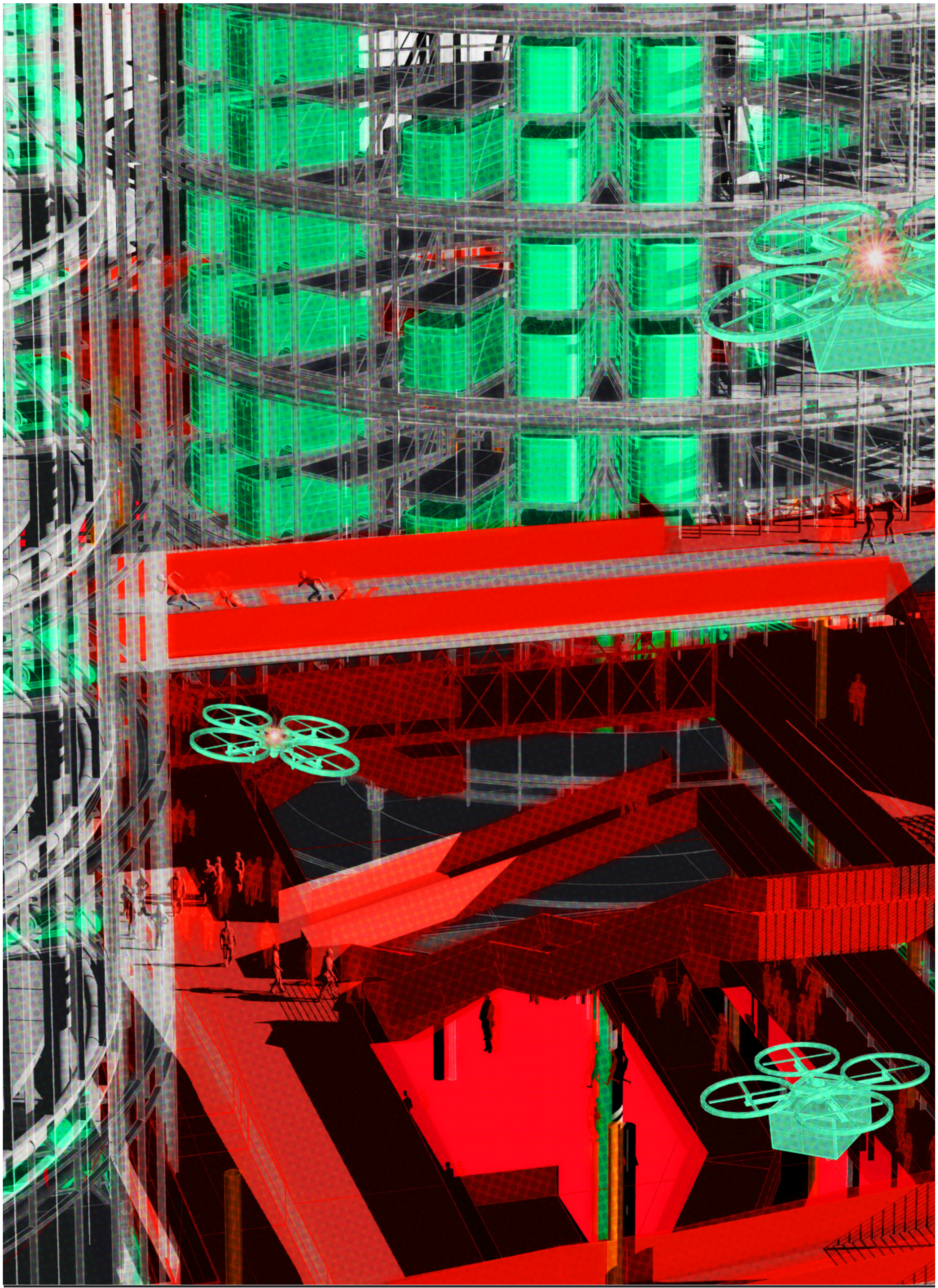
At the Street

The elimination of general automobile traffic has made it possible to modify the typical Vancouver city block in several ways. First, Cambie and Beatty streets have been narrowed to approximately 10 meters. This allows the central laneway to widened, creating a new street within the center of the block. The commercial space that lines the street is broken by opportunities to enter the center of the block. The block interior is effectively a courtyard, surrounded by commercial and public space. Pedways connect levels overhead.

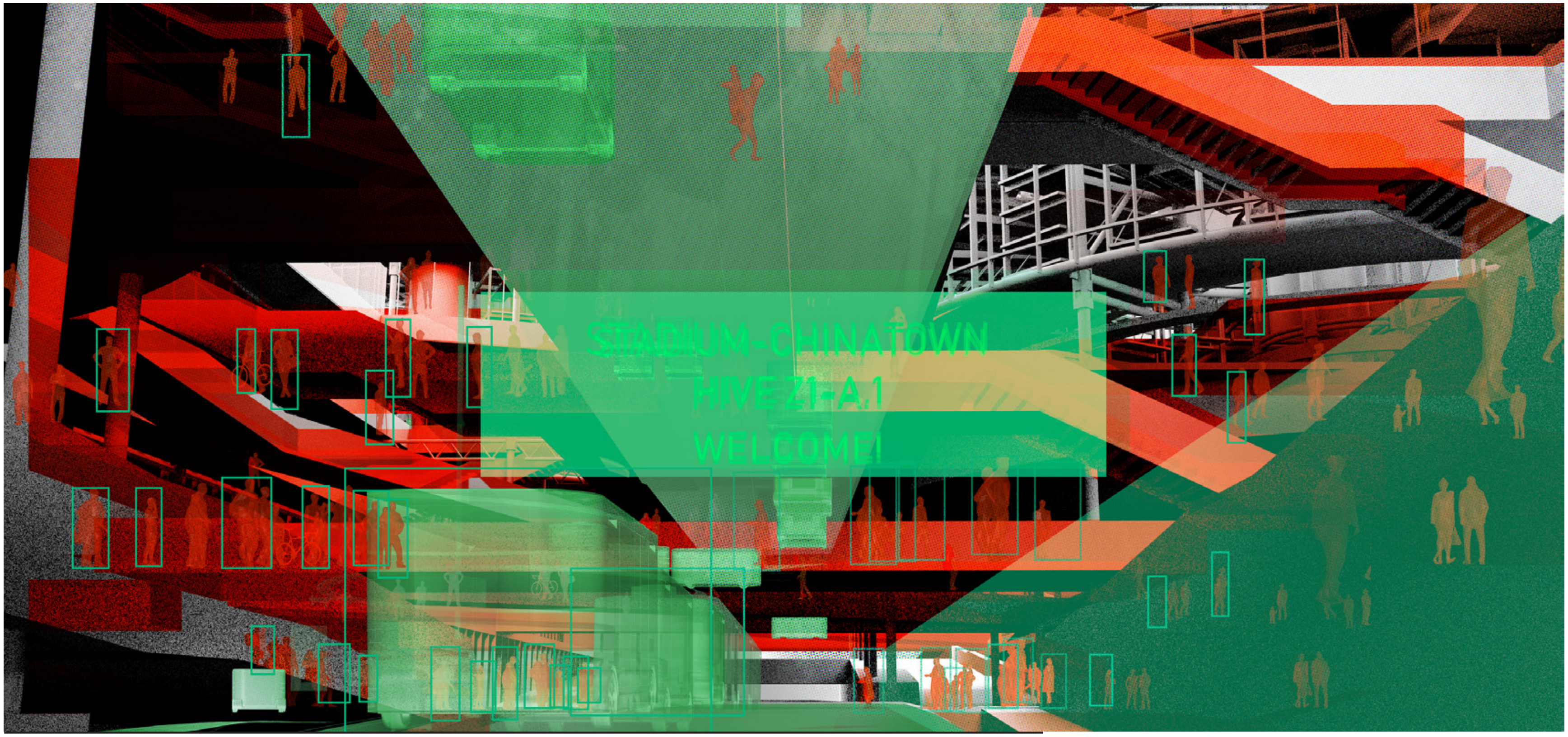
Above the Street

A multilevel market and multifunctional space occupies levels 2 and 3 of the hive. It is accessed via public elevator or the system of ramps and pedways that comprise the multi-level public space. This system extends over West Geogia Street at both Cambie and Beatty Streets, making it possible to cross West Georgia without coming into contact with automobile traffic. Occupying levels 4 and 5 there is a hardscaped public park comprised of a south-facing sun deck and multi-functional space, a running track and a set of courts that can be reconfigured for basketball, volleyball, tennis or badminton. A generous stair leading from the sports courts to the running track functions as bleachers to watch games or other performances from.

View of block interior depicting interface between active hive tower and multilevel public space. Hive Z1-A.1 combines semi-industrial programs such as parking, storage, and package distribution with public programs that include a rooftop park, farmers market and public block interior. The organization of the hive challenges the way public and private space is delineated at the scale of the city block. Further, it challenges the way recreational, industrial, commercial and residential space is organized at the scale of the city - it combines all four in a single space and makes a spectacle of their interaction and function.



Close-up of multilevel public space within block interior. People run on the track and traverse from one side of the block to the other via pedways. Delivery drones fly overhead.



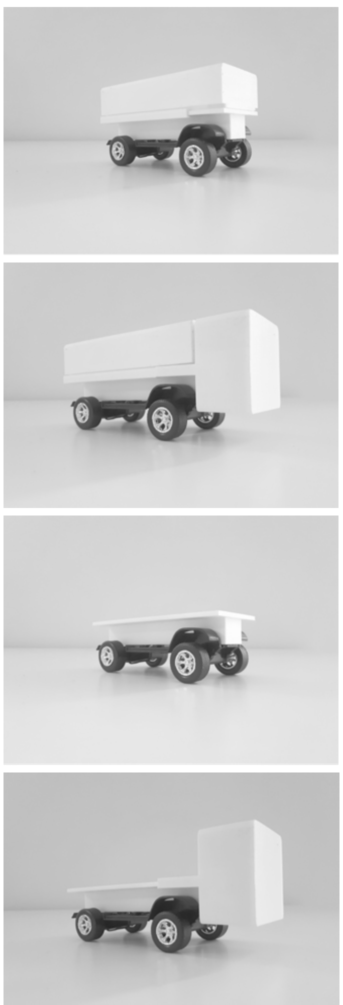
Below grade transit terminal and underground street.

Assimilation

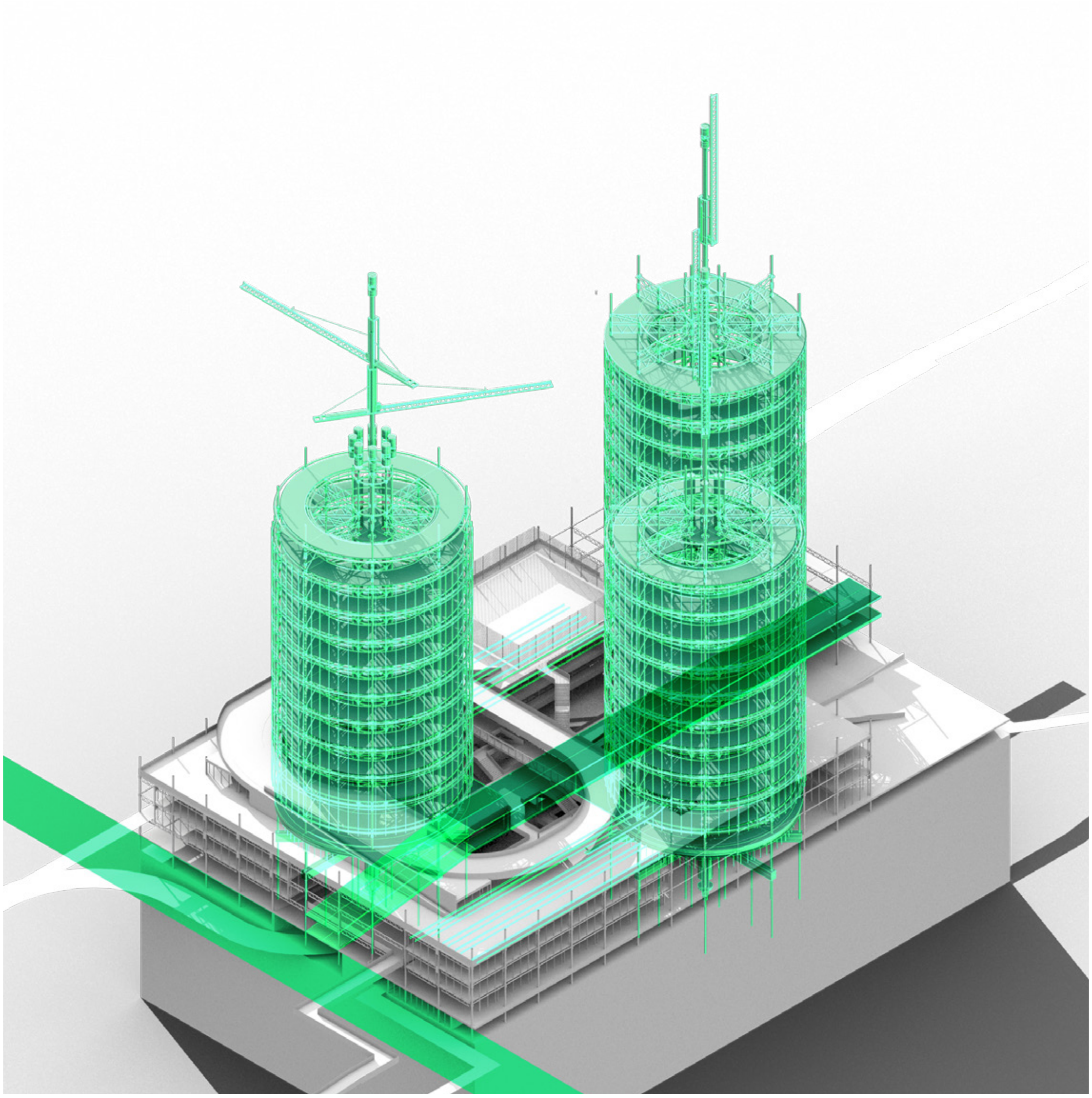
The assimilation of exiting programs on and around the site as it currently stands are developed within Hive Z1-A1: parking, a distribution center and the Vancouver farmers' market. Each program has been adapted to the autonomous vehicle and reimagined as an automated process. Parking and distribution, typically spatially demanding and horizontal processes, have been vertically systematized and radially organized.

Parking/Transportation

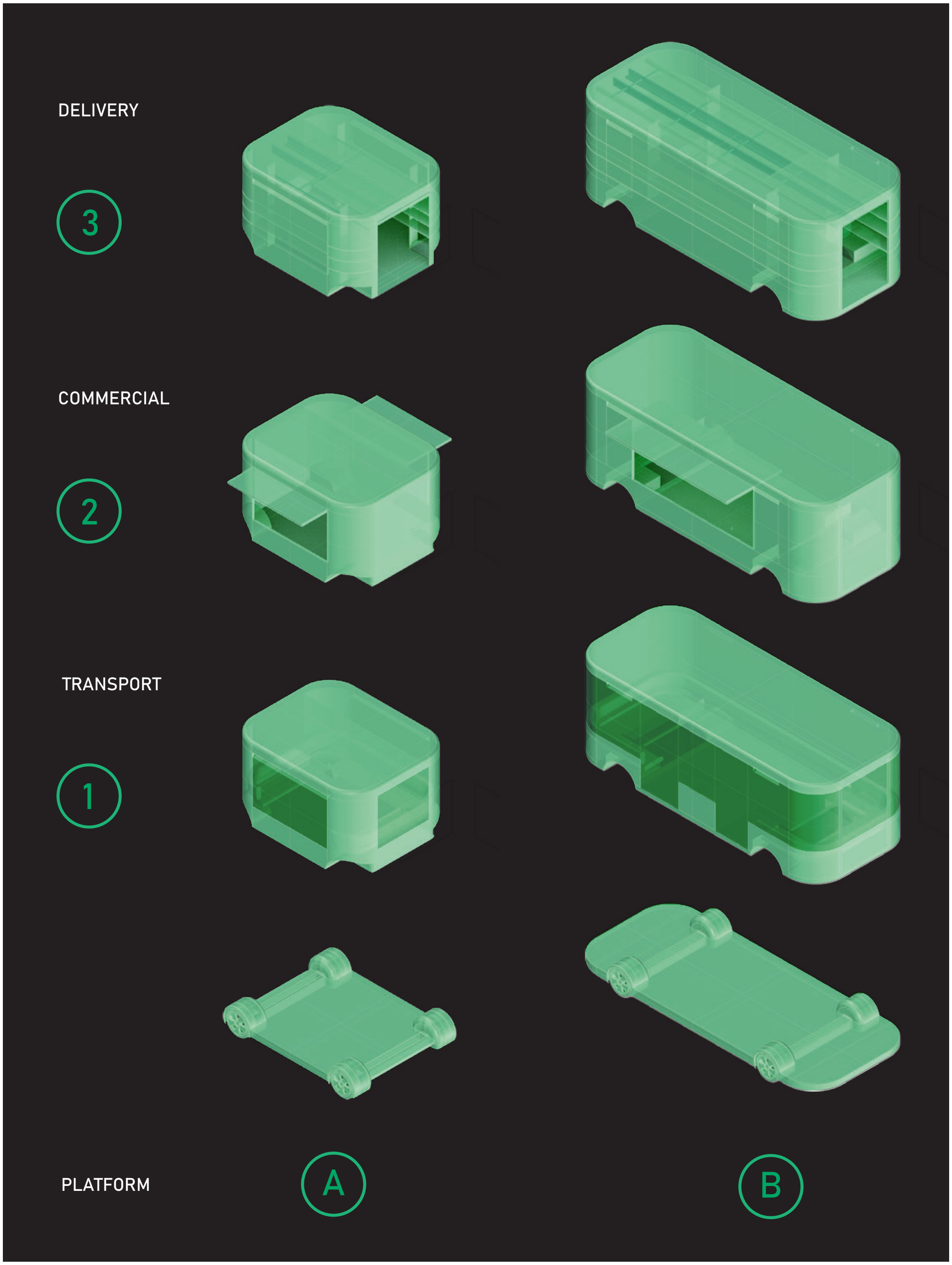
Twenty-first century autonomous vehicles will have a range of capabilities that exceed those of the twentieth century automobiles. Because autonomous vehicles do not depend on a human driver, vehicles controls can be separated from the passenger or cargo cell to create a modular vehicle system. Such a system is comprised of a platform containing the environmental sensing software and hardware needed for autonomous capability, the battery pack, and electric motor(s). A single platform is compatible with a multitude of modules designed according to the needs/specs of the client. In the case of this thesis, three modules were explored in two sizes: a public transit module, a commercial market/ food truck module and a delivery module. These modules can be stored separately from the platform.



Model of modular vehicle featuring a universal platform capable of accepting specialized modules



Modular vehicle of the future separated into a universal platform and a specialized module. The sequence parking sequence is as follows: When a vehicle determines that it needs to return to the hive to charge or otherwise, a communication link is established between the two. The hive network then instructs the vehicle which hive to go to. Upon arrival, all passengers must first exit. The vehicle then travels inside and goes to the hive tower it has been directed to. Driving onto a rotating platform, the vehicle is carried to an available elevator. Once on the elevator, the platform is separated from the module to be stored separately. The elevator then carries the pair to an available stack. The platform is capable of driving into the stacks under its own power whereas the module is transferred to the stack by a robot integrated into the design of the elevator. Upon completion of this task, the elevator moves onto the next.



Modular vehicle of the future separated into a universal platform and a specialized module

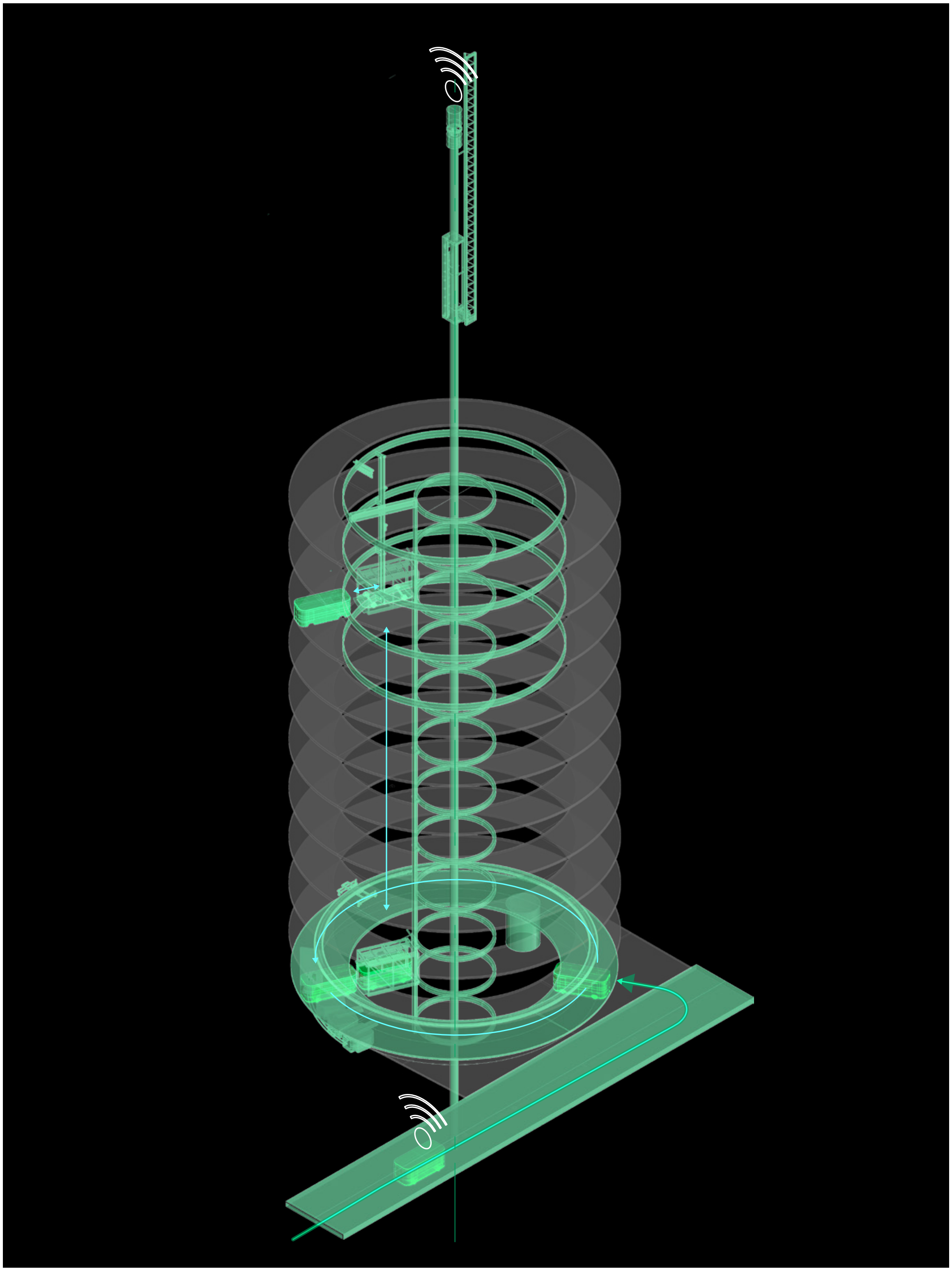


Diagram of automated hive parking sequence

Cross section of Hive Z1-A.1 depicting Hastings Line transit station and multi-level public space

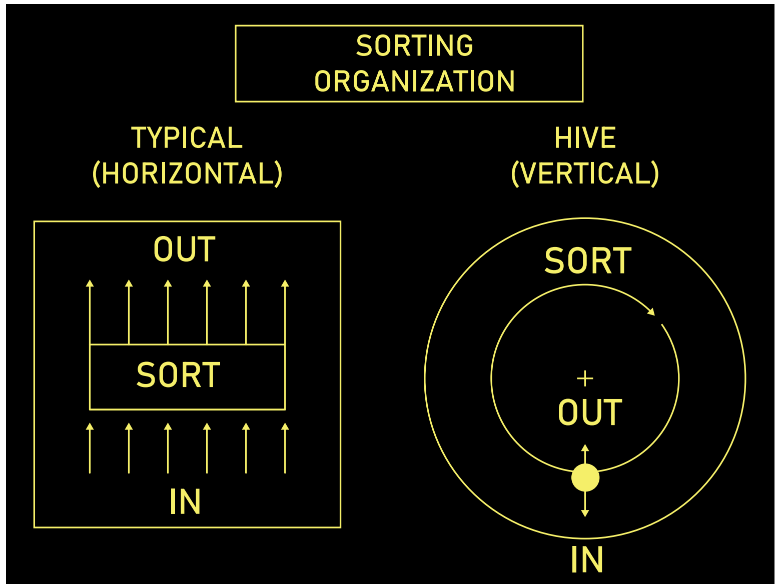


Diagram of typical distribution center organization vs. hive distribution center. The sorting sequence for typical distribution center is linearly organized. At the receiving phase (IN) packages are unloaded onto a conveyer belt. As the packages are transferred to the sorting phase, they are scanned so that they can be sorted according to the postal code of their destination. Within the sorting phase, packages travel along a series of conveyer belts that direct them to the truck that will be responsible for their final delivery. Arriving at the truck, packages are loaded according to order of delivery. This process contrasts with that of the hive, which is radially organized. When packages arrive at the hive, they are pre-scanned and sorted within a module. The placement of the module within the hive is done in a way that the contents within it can be efficiently transferred to the module of their final destination. Sorting robots transfer presorted cases of packages from module to module. When a module is full or the turnover time is reached, the module is placed on a platform and goes to deliver packages.

Distribution

The distribution center program - typically a linear, horizontal process - has been reimagined as a radially organized and stacked process.

The hive has several advantages: First, the facility is much more compact. A standard facility occupies an area of 4600 square meters or more, whereas a hive tower occupies

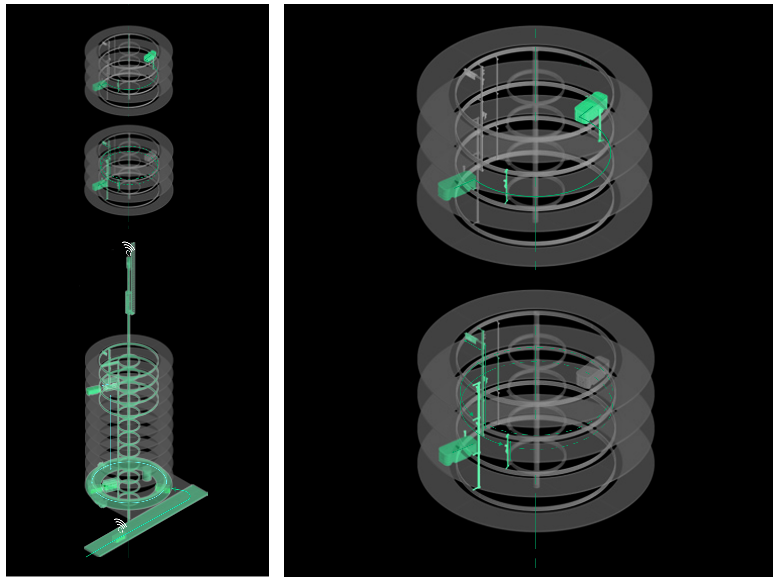
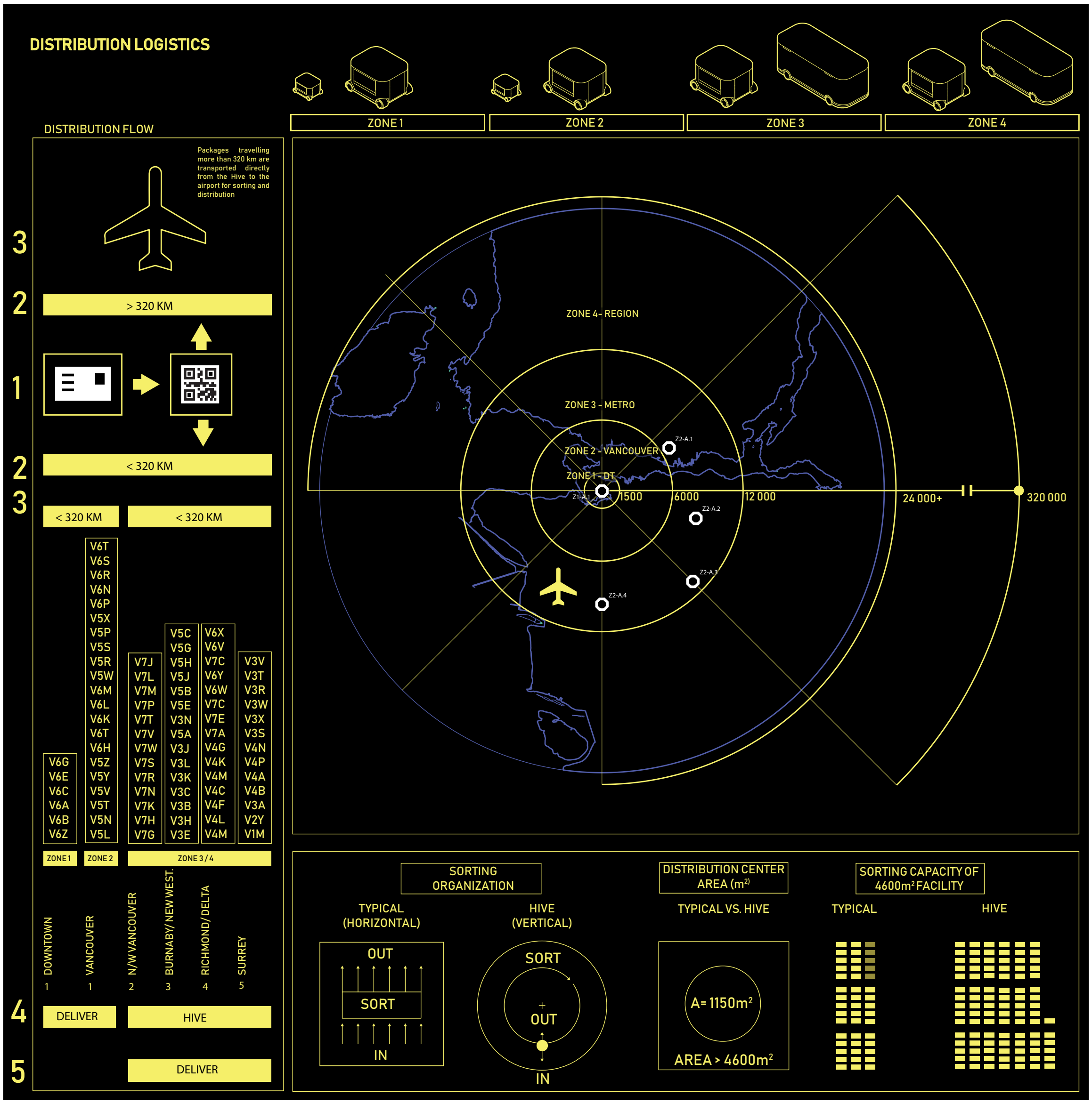
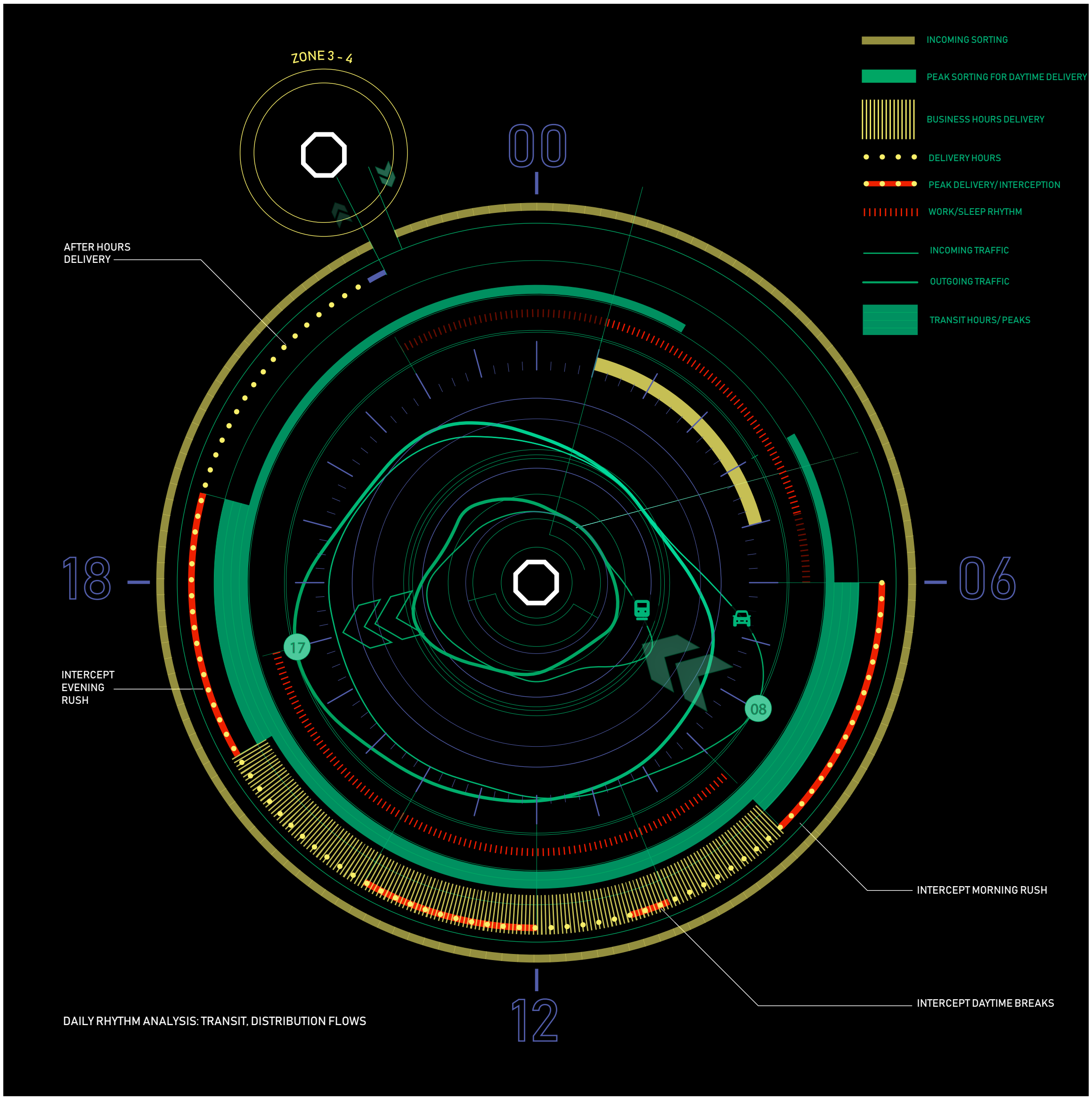


Diagram of distribution and sorting process

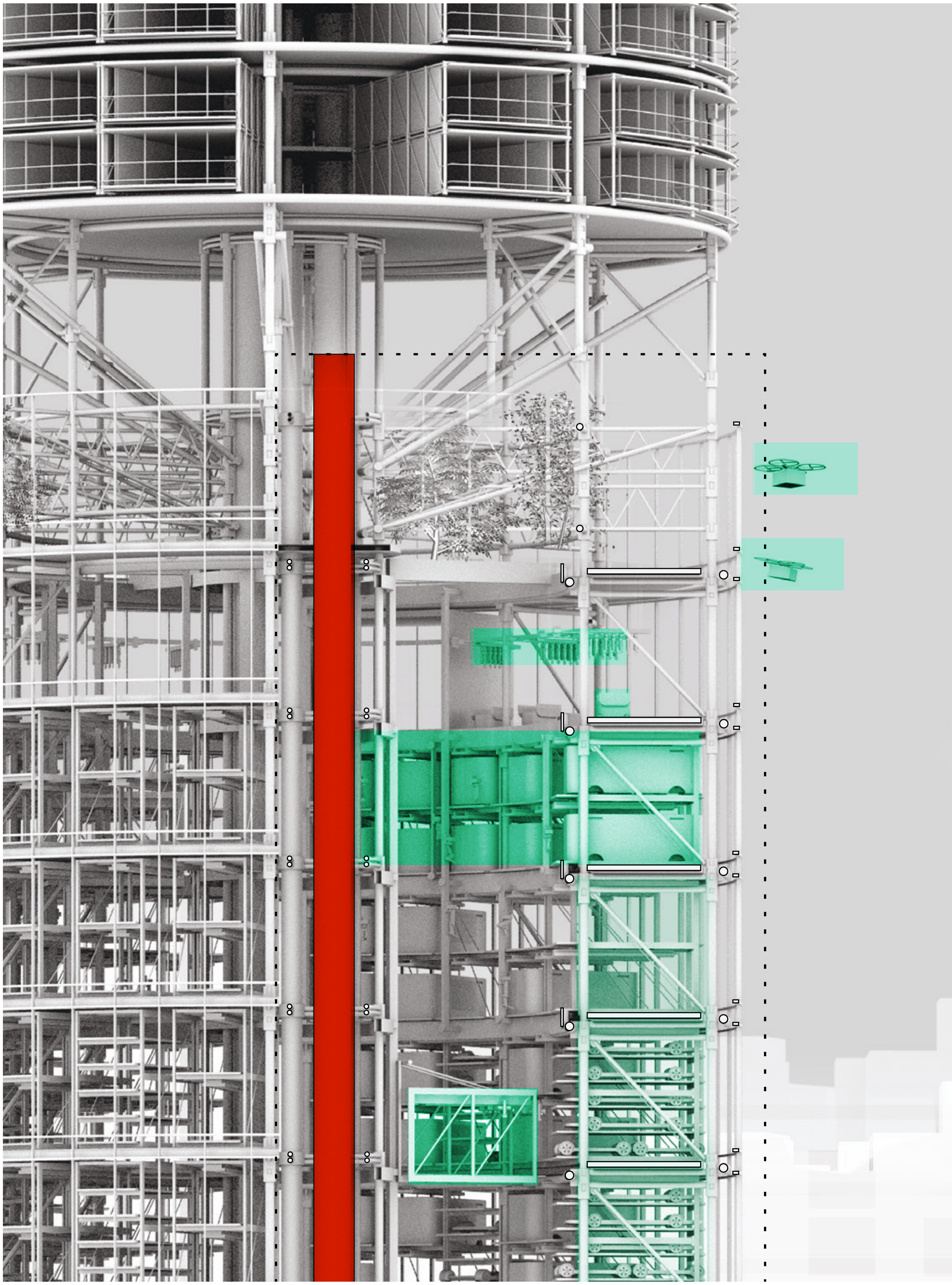
1150 square meters - one-quarter the area of a typical distribution center. Secondly, within that 1150 square meters, the hive can sort up to 24 vehicles at a time. Therefore within an area equivalent to a standard facility, up to 96 modules can be sorted. Thirdly, packages are pre-scanned and sorted before they arrive at the hive for final sorting. The only sorting step that takes place within the hive is the transferal of package groups from the module they arrived in to the module they will be delivered in. This is done by a team of intelligent robotic sorting arms. Fourth, stacking modules and arranging them radially is spatially efficient. Because packages are pre-scanned and sorted, modules can be arranged or re-arranged within the hive according to their contents in order to make the sorting process as efficient as possible. The compactness of the hive and the efficiency gained through the employment of autonomous vehicles and robotic sorting arms means that a distribution center can be located within the city center and can be paired with many other programs.



Diagrams of distribution center logistics and spatial organization. Packages travelling more than 320 km go directly to the airport for sorting and delivery. Packages travelling less than 320 km are sorted according to zone. Packages destined for zones 1 and 2 are sorted and delivered. Packages destined for zones 3 and 4 are transferred to another hive for sorting before final delivery. (basemap from Google Earth)



Temporal flow analysis of transportation and distribution. Peak transit hours, business hours and sleeping hours create a framework for how Hive H1-Z.1 manages the flow of goods and people. Periods for delivery interception are identified when people commute to/from work, during morning coffee breaks, or at lunch. During these periods, delivery robots might meet people at a convenient location or people might pick up their packages directly from the hive. Package sorting takes place around the clock, but packages destined for zones 3 and 4 are transferred every night at 10 pm for sorting and delivery. (data from Government of British Columbia, Ministry of Transportation and Infrastructure; Translink 2018 Service Transit Performance Review)



Sectional view of hive Z1-A.1 depicting the distribution and sorting center located at the upper levels of the parking structure

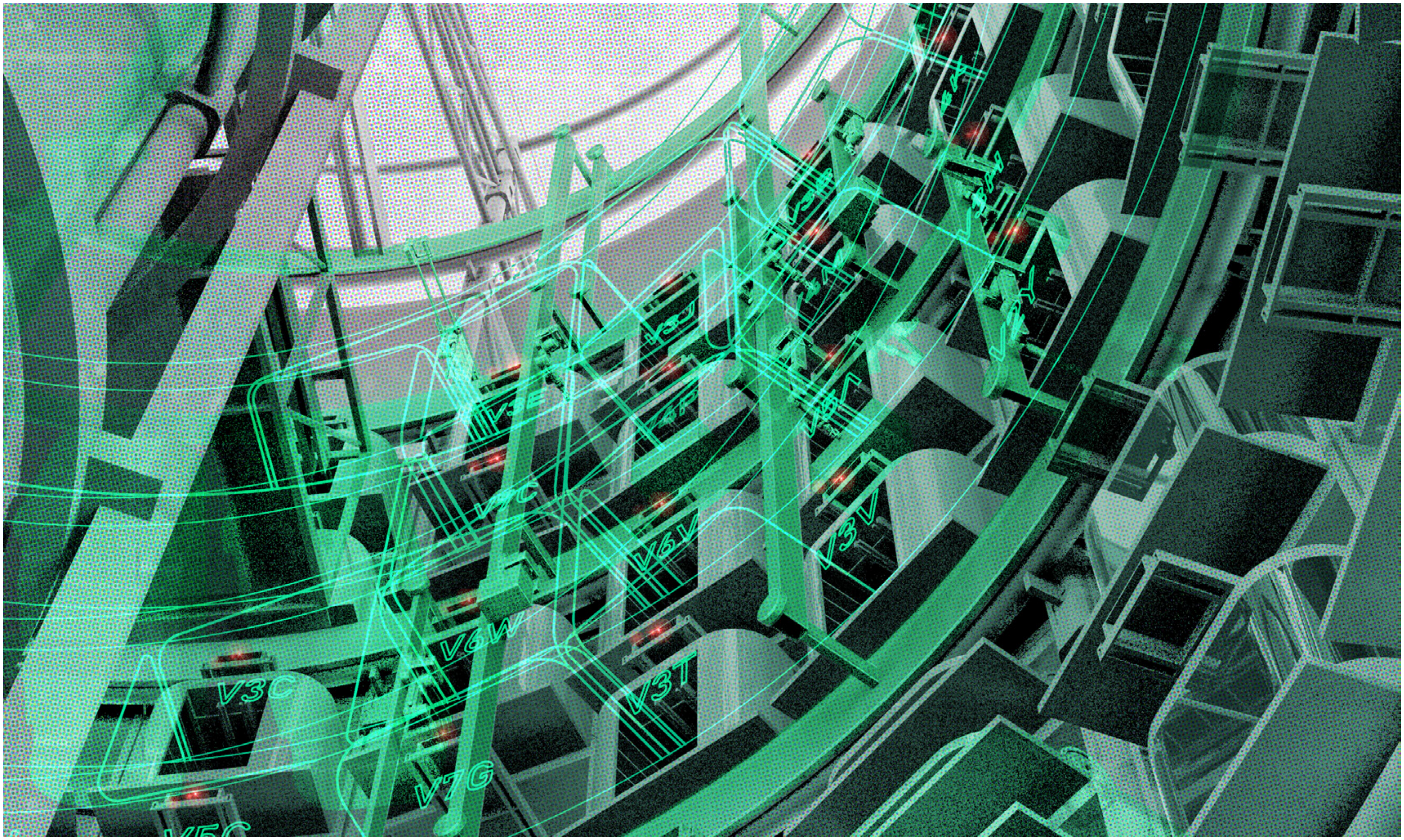
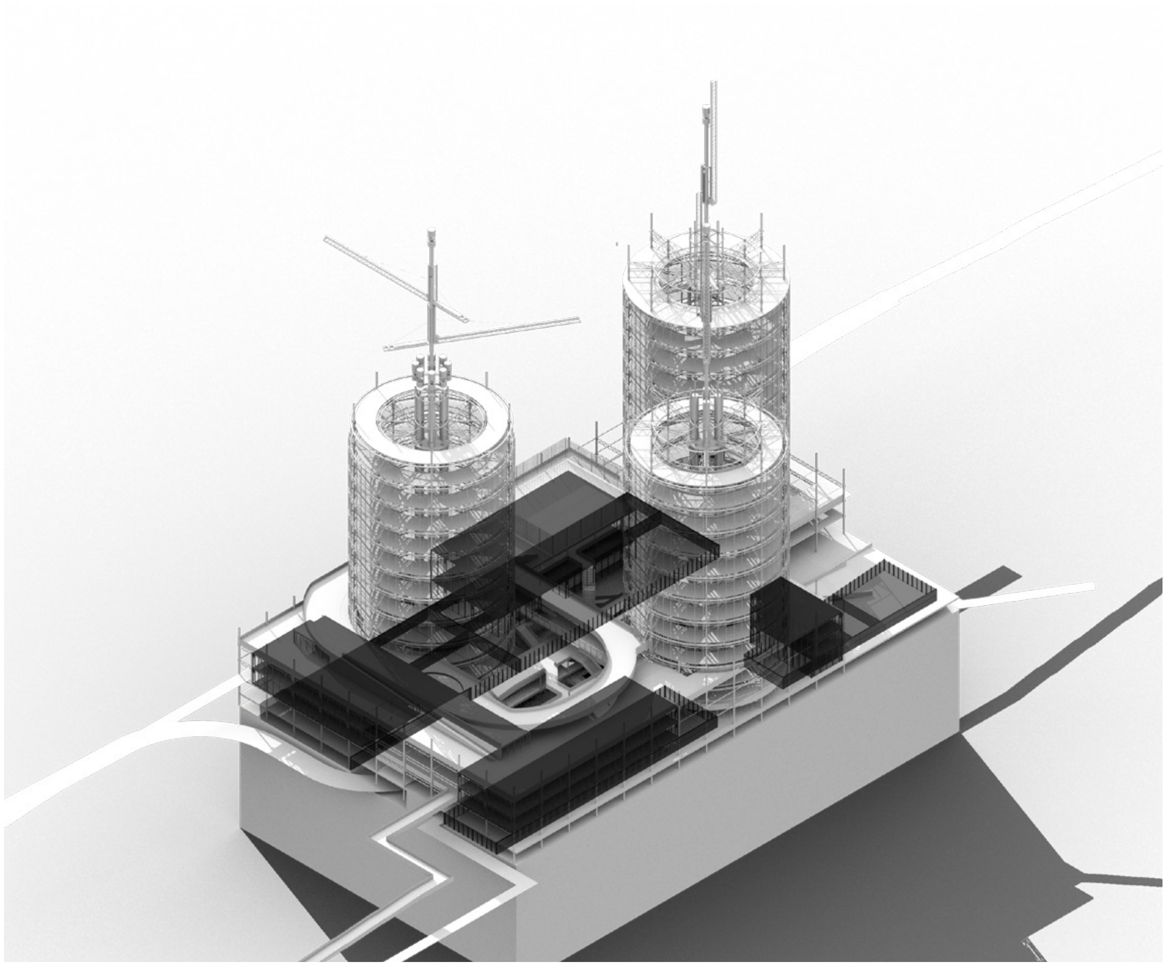


Illustration of distribution center



Isometric view of commercial space within hive Z1-A.1

Market

The Vancouver farmers' market has been reimagined as part of the hive. In this scheme autonomous vehicles drive to agricultural sites where they are loaded with farmers' produce and products. Once loaded they return independently to the hive and the module is transferred from the hive tower to market space by a robotic apparatus. Modules are arranged into different configurations depending on how many are present. The farmer can ride along within the module or arrive independently to sell their products.

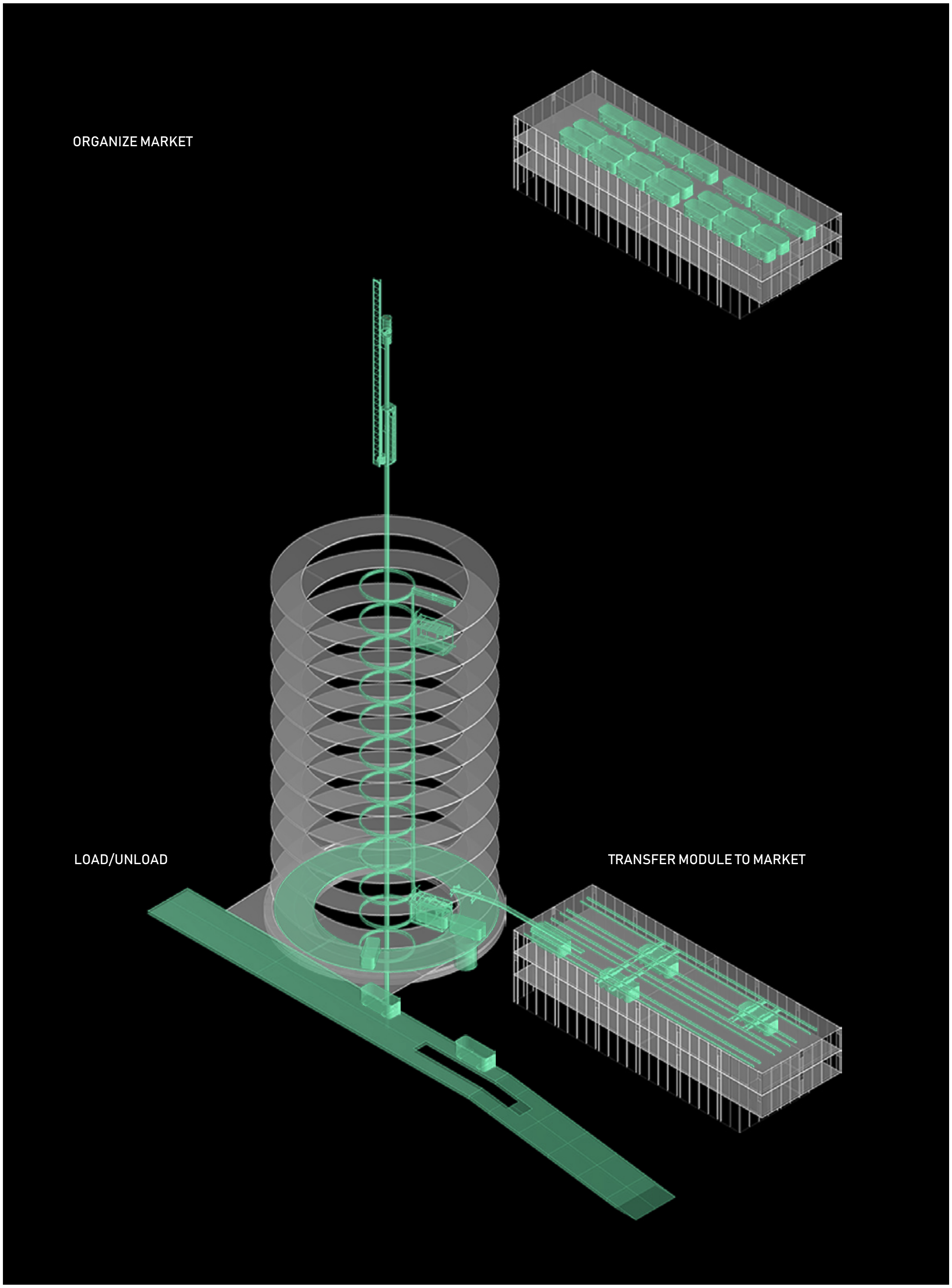
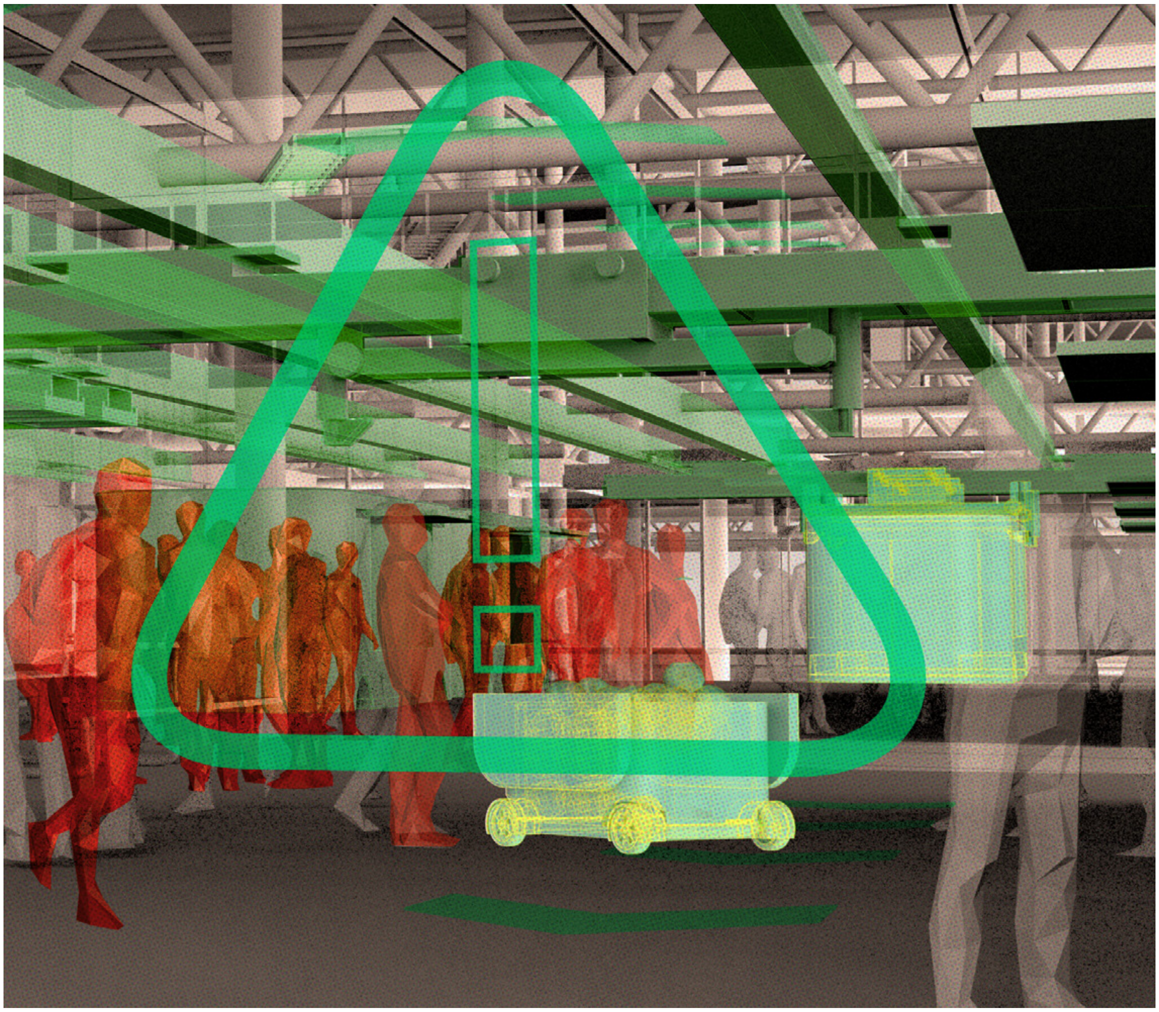


Diagram of transfer sequence from hive tower to market

Perspective section of hive interface between public space , hive tower (left) and market (right)



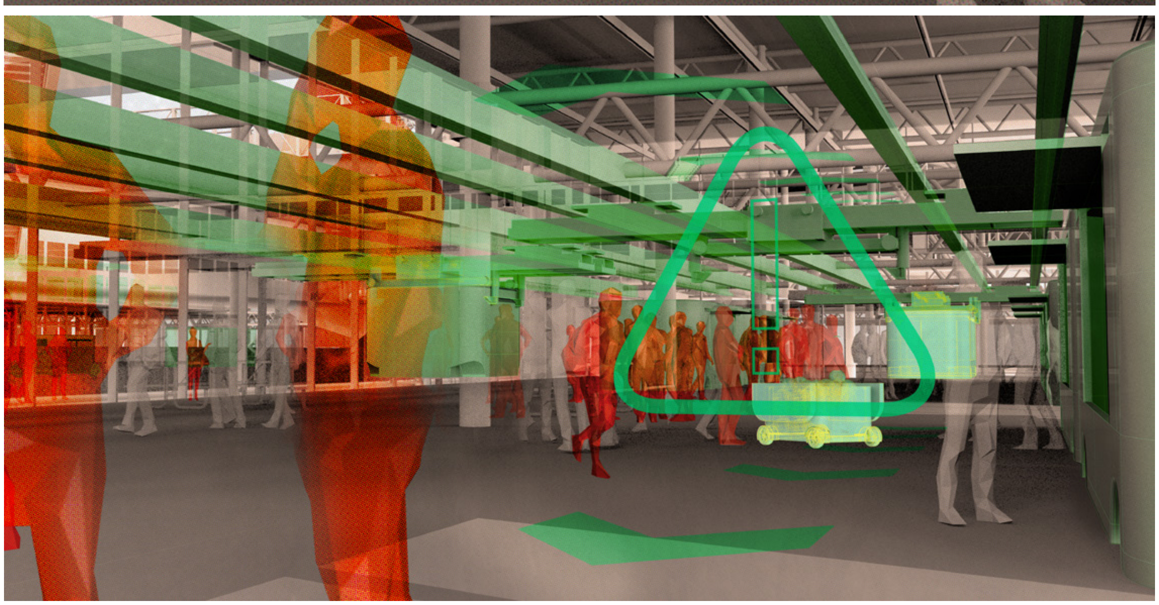
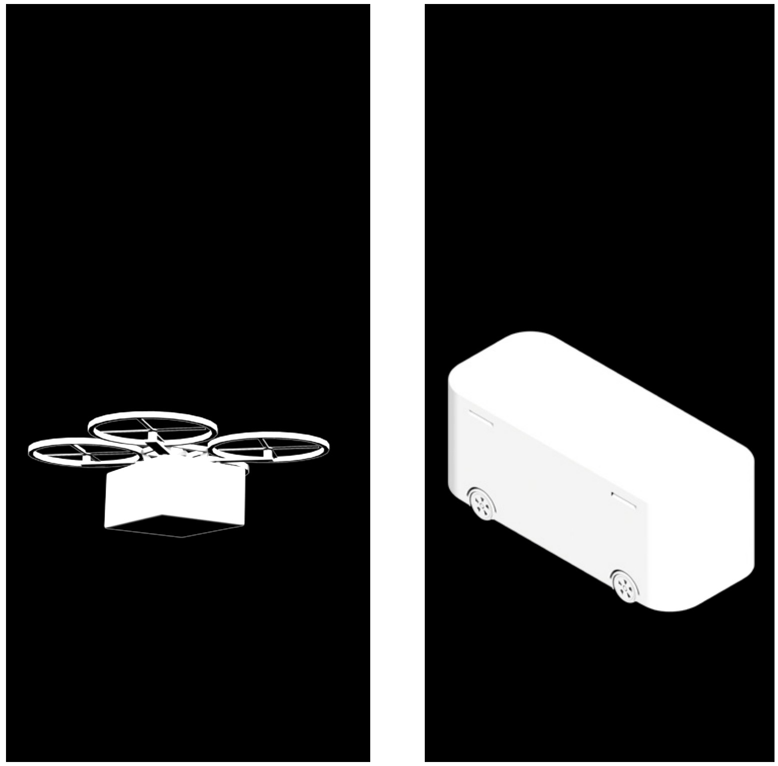


Illustration of level 2 market space depicting module being transferred from hive tower to market.



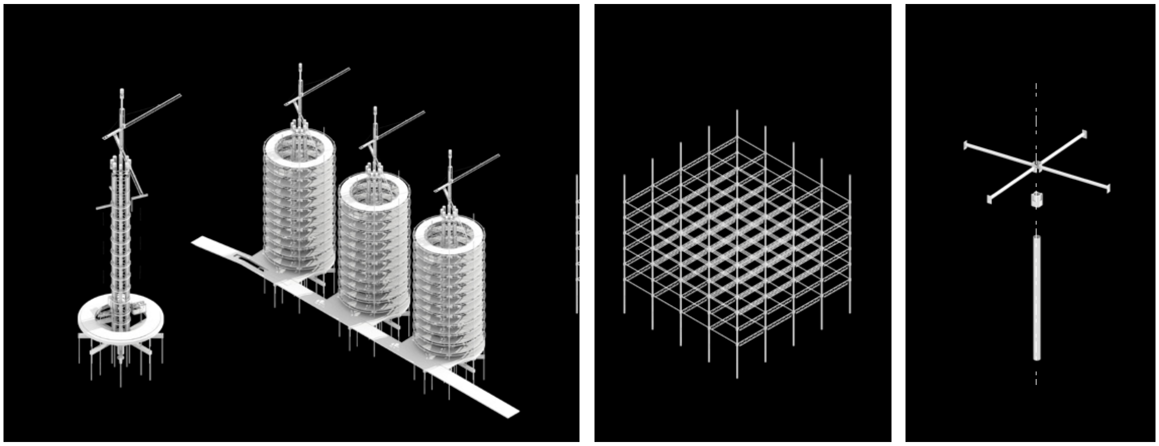
Delivery and transportation drones

Respond

The Hive is capable of responding to its context as it changes through time or due to economic pressures and demands. This can occur through an integrated internet system, a modular construction system and automated assemblies.

Internet Integration

The hive is integrated into the transportation and communication internets. This integration allows the hive to communicate with other city infrastructures, manage the flow of goods and people, and coordinate the movement of air and land based autonomous vehicles. These capabilities make it possible for the hive to coordinate its own expansion, retrofit and deconstruction by instructing autonomous vehicles to transport construction materials.



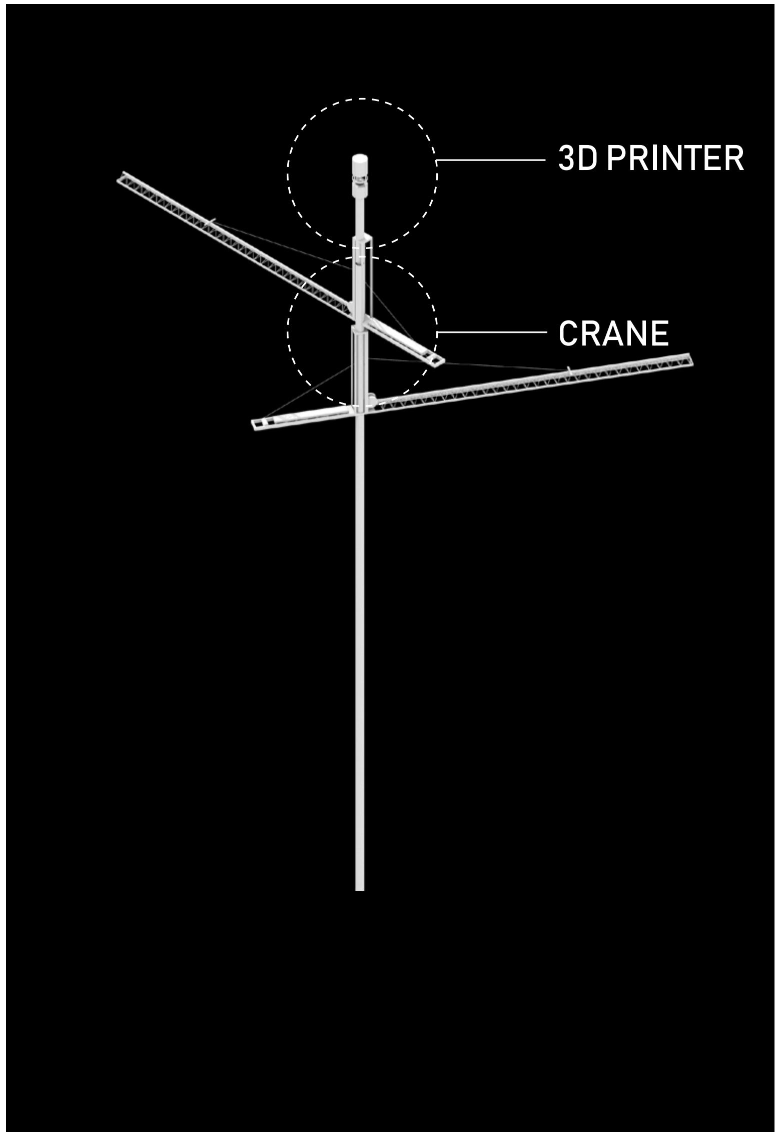
Elements of modularity (from left to right): repeatable core, organizing spine, expandable grid matrix, modular construction base units

Modularity

Hives are an assemblage of modular units that allow for repeatability and expansion. The first modular unit is the central circulation core. The innermost circumference of the core is occupied by vertical circulation for people. Several cargo elevators, capable of rotating about the center are attached to the exterior of the core. Storage, housing, commercial space and range of other programs can be attached to the core.

Autonomous vehicles access hive towers by way of a central spine along which towers are organized. This spine can be as long as necessary and hive towers can be numerous as needed.

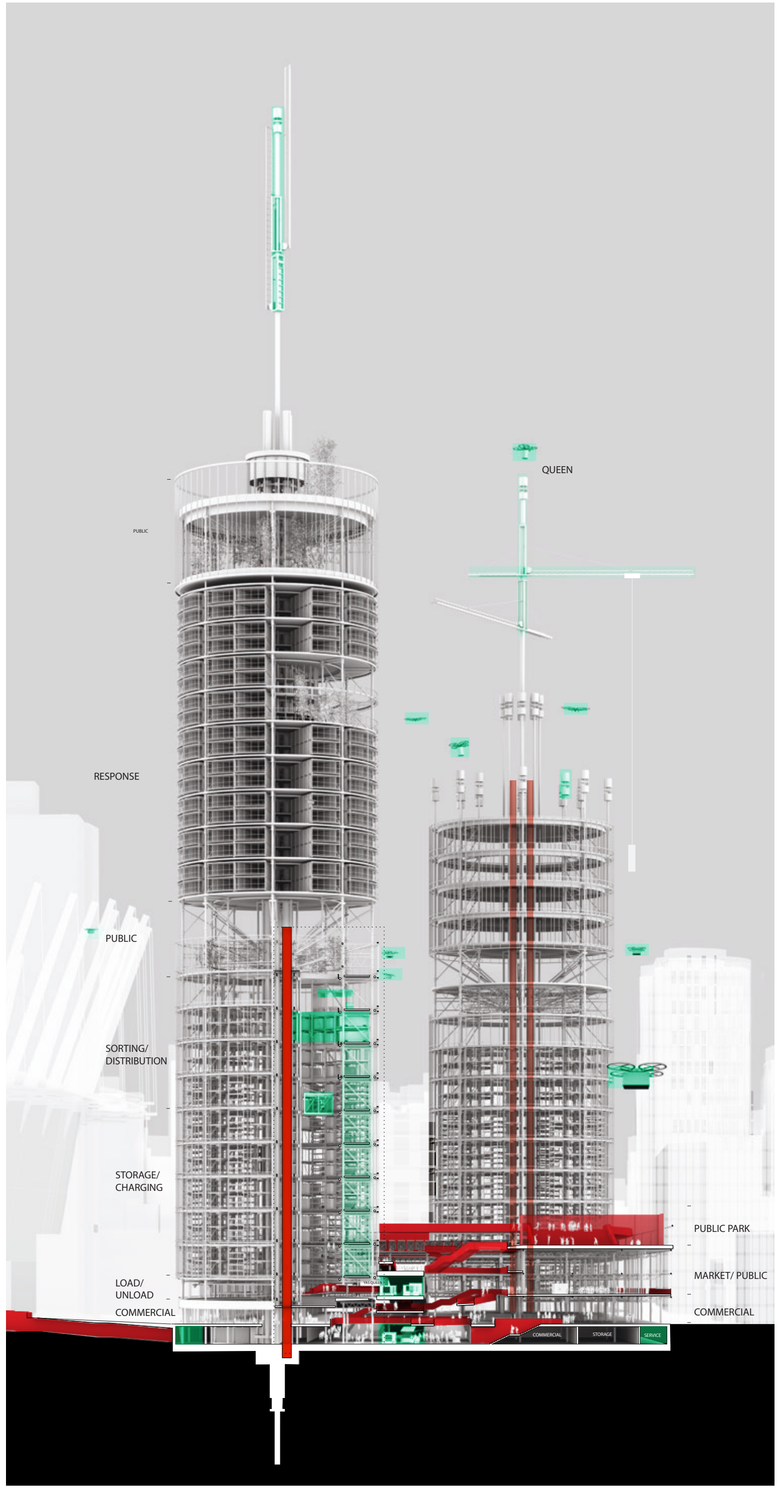
Hive towers are surrounded by a grid matrix . The grid is constructed from 3 elements, i) a 3D printed column, ii) a connecting element, and iii) custom spanning element. The grid is capable of growing upwards and outwards, functioning as structural apparatus for distributary robots such as those in the market, pedways and parks, or apartments and studios.



The Queen - a composite of a 3D printer and a pair of cranes that work together to assemble the hive

Automated Assembly

Construction of the hive is facilitated by the queen - an assemblage composed of a 3D printer and a pair of cranes. The 3D printer rests atop the central column of the circulation core, printing the column from steel as the building grows. Steel filament is replenished by drones. The cranes work together to lift construction materials and modules into place. The fitment of pieces is assisted by drones.



Perspective section of hive Z1-A.1 depicting the addition of modular apartment units at upper levels (left) and in-progress construction of upper level office space (right)

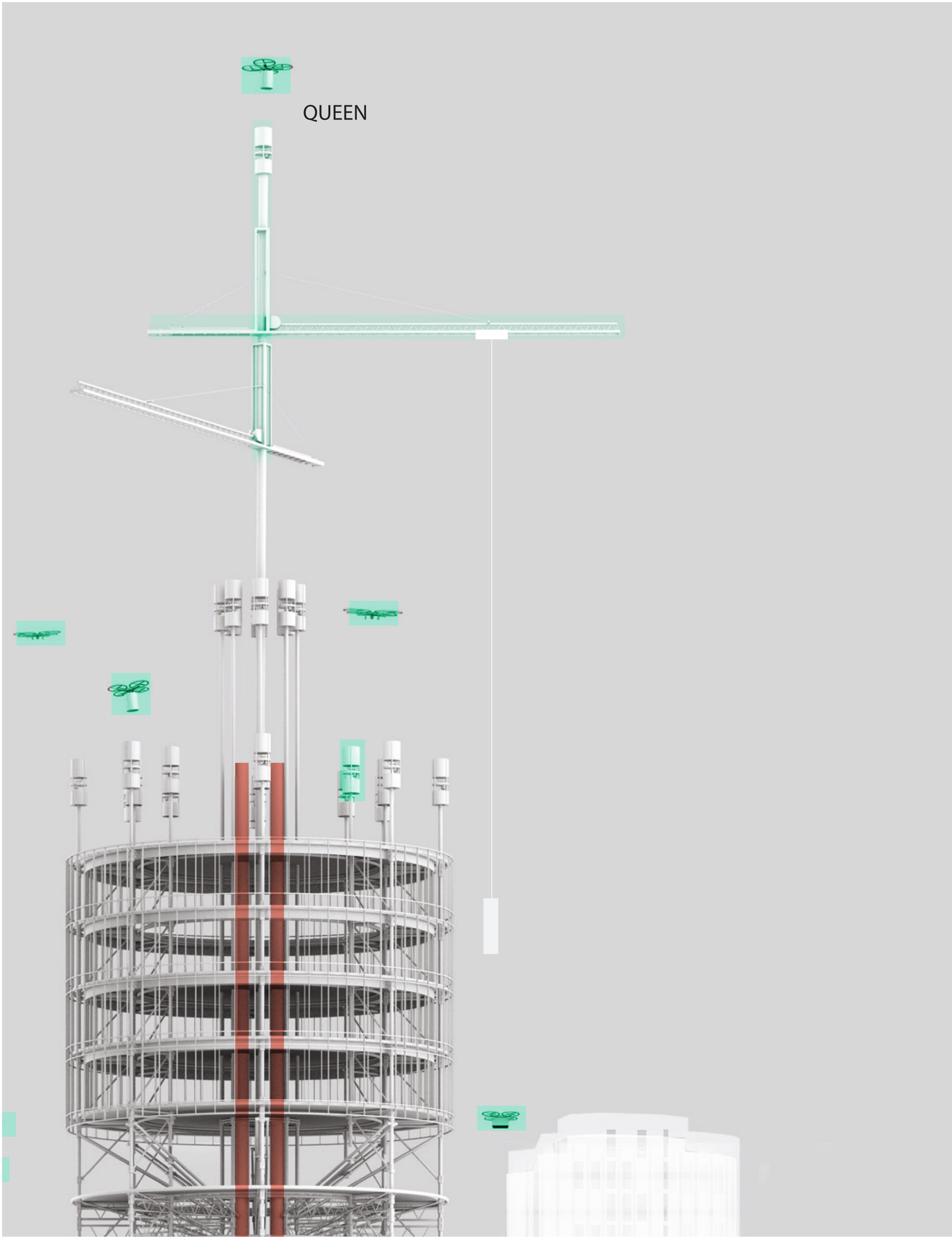


Illustration depicting the Queen assembling office space as delivery drones replenish the steel filament for the 3D printers

CHAPTER 6: CONCLUSION

This thesis explored the intersecting space between automobility, architecture and the city. It has proposed that automobility and the city will continue to co-evolve and that automobility will continue to exert considerable influence on the design and organization of the urban realm. Architecture, in the form of the Hive, has been inserted in this dialogue, framed and explored as a translator between the urban system and the automobile system, capable of mediating between competing visions of how the city could be.

The potential of the Hive has been explored in the context of Vancouver's downtown peninsula, c.2051. It is around this time that autonomous vehicle technology will approach total ubiquity and it is therefore of interest to explore not only how autonomous vehicles and total internet integration might impact the city, but also how the city might employ these, and other related technologies to achieve its own goals. It has been proposed that through the introduction of the Hive – an intelligent network of inter-system/modal hubs - the movement of autonomous vehicles transporting goods and people can be coordinated and managed. This capability can in turn facilitate the extrication of space from automobility for use by other systems in a pedestrian city.

A combined method for siting and designing the Hive has been put forward. Shortened to the acronym MARC – this framework evaluates possible sites and guides design decisions based on their potential to Mediate between forces, Assimilate existing program, Respond to context and Connect systems and modalities. The resultant architecture is modular, expandable and adaptable; its growth and potentially its deconstruction are facilitated through its integration into the transportation, communication and energy internets. Through the deployment of the tools at its disposal, the Hive is an active agent in the evolution of the city, capable of making network-coordinated, local scale changes that resonate through the urban system.

This thesis has conceptualized the Hive and a method for its integration and design. While the focus has been on the architectural expression and organization of the system, there is still much more to be explored. First, the impact of the Hive on the pedestrian realm has only been explored insofar as it relates to Connectivity. The potential of the pedestrian realm for purposes beyond transportation is an exciting avenue for further research and a logical next step to this thesis. For example, what function might these new streets serve, how might they be integrated into other systems – agriculture, water collection and filtering, energy production, commerce, public space?

A second avenue for research could be an exploration of the ways internet integration, artificial intelligence, deep learning, data collection, sensing and data analysis will influence architecture and urban systems. The integration of these technologies has many possibilities, among them the potential to create architecture and a city that takes on a life of its own. Lastly, there is opportunity to explore how the Hive or similar mechanisms can utilize feedback to elicit a response and how that response resonates through the city. This thesis has touched on this in only a rudimentary way, proposing for example that gentrification can be responded to with low cost housing or that an entertainment district can be nurtured through the introduction of exhibition/

performance space. If the relationship between action-reaction in the context of the city was well understood, then the Hive could be much for effective at engineering change within the city.

This thesis has not questioned the role nor the value of technology in shaping the future. In reference to autonomous automobiles, it has been optimistically assumed that the technology will function as intended, and that the data these vehicles will no doubt be capable of collecting will be used neutrally and anonymously. However, it is easy to also imagine the insidious effects of intelligent, data collecting robots roaming the streets. It might be that future is a place where jaywalkers are instantaneously identified by an autonomous vehicle's facial recognition software and issued a charge for their petty crime, or, more seriously, where autonomous vehicles are hacked and weaponized by malicious forces. More disturbing is the potential for such events to become normalized within society and ignored by policy makers and special interest groups. Consider the fact that, globally, an estimated 1.24 million people die every year in automobile accidents (World Health Organization 2013, 1). While considerable effort is made to regulate automobile safety standards and ensure a safe environment for all road users, it is accepted that automobility comes with risk of casualty - death is part of the package. Unfortunately, it is possible that society will similarly grow to accept casualty, data breaches, or the occasional hacking incident as part and parcel of autonomous automobility.

In consideration of the threat to human security that autonomous vehicle technology poses, perhaps it is necessary to think about how the delineation between auto-space and people-space is conceptualized. This thesis proposed the pedestrianization of the city as part of the Hive system. Within this system, a geo-fence segregates the movement of automobiles from that of pedestrians. What is being proposed is that perhaps it is not just a geo-fence, but more of a firewall, designed to protect the people of the city from unnecessary surveillance and cyberterrorism. Strengthening the language used to discuss and conceptualize such a digital barrier brings attention to the potential consequences of allowing autonomous vehicle technology to be critically integrated into daily life while at the same time providing a potential framework for design. As it is in the interest of public health, this suggestion should be should be taken seriously by potential developers and policy makers alike.

The optimistic attitude towards technological advancement presented in this thesis is not to negate its more problematic effects. It would be naive to believe that something as complex as autonomous vehicle technology could be implemented into something as complex as the urban system easily and without issue (potentially serious issues). However, technological advancement is one of the principal ways that society seeks to address the challenges it faces. Autonomous vehicles being a textbook example of this. Advocates of the technology promise it will virtually eliminate traffic congestion and traffic related casualties, that it will eliminate the need for curb-side parking, that it will make it possible for people of all levels of mobility to access the city, etc... While all of this may be true, it is unlikely that problems will not arise at a later time, just as they did as 20th century automobility evolved. In the event of such, it is likely that society will once again seek and adopt a technological fix. In the context of this pattern, this thesis has taken a stance on where and how autonomous vehicle technology should be implemented in the city. As much promise as the technology holds, it would be wise to not permit its free reign and unmitigated advancement. Instead, efforts should be made to limit the movement of automobiles while exploiting their core functionality - force the automobile to work for the city, not the city to work for the automobile. In doing so, perhaps more sustainable and equitable ways of living will emerge.

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