DRONE ENABLED 3D URBANISM

by

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ABSTRACT

This paper examines how urban architecture might be affected if the widespread use of drone technology were to partially replace conventional transportation infrastructure with multidimensional systems made up of multilayered aerial highways. How would building typologies and urban environment have to be rearranged to ensure efficient work of these systems.

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1. INTRODUCTION

The rapid evolution of drone technologies and their gradual integration into our everyday lives raises many questions regarding whether we are ready to have fleets of unmanned aerial vehicles crowding our skies. Chief among these have to do with their societal impacts and the ability of the urban infrastructure to cope with these impacts.

Modern drones can perform a broad range of tasks, indeed everything from aerial photography to the delivery of goods to police surveillance. The benefits include increased mobility and lower infrastructure costs. However, regardless of the task drones are likely to perform, they will significantly impact our living environment, transforming cities into habitats for unmanned flying machines. The changes to urban infrastructure will be major. The main transportation pathways will no longer be situated on the ground, and the spatial organization of cities will be reconfigured by the addition of a third dimension. This, in turn, will alter how access and supply infrastructure is designed, as well as how buildings connect to the surrounding urban environment.

Drones can both enable and facilitate 3D urbanism in a different non-conventional way by providing a flexible and efficient means of transportation within increasingly crowded cityscapes. They can also densify those areas of a city previously underused due to traffic congestion, decreased accessibility and/or lack of amenities. And while drones have the potential to improve the efficiency of transportation systems, also importantly they will change the nature of the built environment requiring it to step beyond two-dimensional arrangement, raising questions regarding how, as architects, we should respond.

This paper examines how urban architecture and planning might be affected if the widespread use of drone technology were to partially replace conventional transportation infrastructure with multidimensional systems made up of multilayered aerial highways. How would building typologies, forms and configurations have to be changed to accommodate these systems.

Transportation technology has always been a powerful force in shaping and transforming cities. Just as motor vehicles changed the physical imprint of cities at the beginning of the last century, drones will likely modify urban spatial organization. While automobiles led to the massive growth of cities and economies and were celebrated as the “ultimate human freedom to move from place to place” (Jackman), they also segmented the urban fabric. As a result, new freeways slicing through cities became a major contributor to social segregation, as residential communities were divided by major roads.

Many cities were not designed to accommodate automobiles, consequently many areas, especially those located within historical enclaves, became difficult to access. Today, when many contemporary metropolises are planned, transportation arteries are one of the key factors that guide urban development; nevertheless, even this approach to planning does not guaranty efficient transportation infrastructure. With continuing suburbanization, highways engulf more and more space in metropolitan areas; indeed, there are cities in North America where roads cover more than 50 percent of the total area (La and Maas 38).

If the introduction of drones is to address some of today’s major urban problems, urban architecture and infrastructure will have to be adapted so as to accommodate this technology. Developing building designs capable of accommodating drones as well as addressing possible societal impacts will be essential if cities of drones are to become a reality.

2. CONTEXT

2.1 Technological

Technical Aspects

Until the beginning of the 21st century drones, known as unmanned combat aerial vehicles (Fig. 1), were used solely as aerial robots for conducting surveillance and military strikes (Rao et al. 3).

Figure 1. Predator Drone

"The shift from exclusively military drones to civilian applications can be traced to the aftermath of Hurricane Katrina in 2005. In the broad rescue effort that followed, military drones equipped with accurate infrared cameras were widely recognized as a useful field asset. This led to the Federal Aviation Administration (FAA) first issuing certificates to allow M7RQ series military drones to be used over civilian skies in 2006" (Rao et al. 3).

Since that time, the market for recreational drones has grown rapidly. The increasing popularity of drones, also referred to as Unmanned Aerial Vehicles (UAVs), has led to dramatic technological improvements. Today, there are hundreds of different types of drones available that vary in size, range, motor types and equipment.

Drones fall into two categories: rotary wing (Fig. 2) and fixed wing (Fig. 3) ("Fixed Wing"). The essential difference between the two types lies in their mechanical complexity, load capability, and takeoff and landing procedures. While fixed wing drones require a runway to facilitate takeoff and landing, rotary wing drones need only a landing pad, since they can take off, hover and land vertically, which represents a significant upside for urban use. In addition, multiple-rotary wing drones have greater maneuverability. A notable advantage of the fixed wing UAV is its aerodynamic qualities that are associated with a relatively simple structure that allows for higher speeds, making them ideal for long-distance intercity travel (Lagatic).

Figure 2. Rotary wing drone

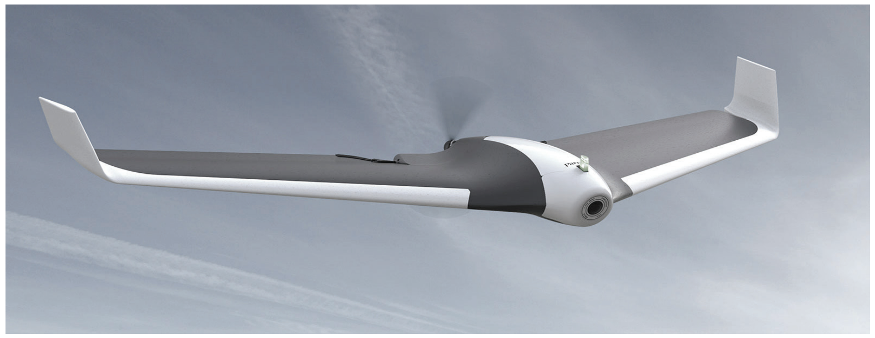


Figure 3. Fixed wing drone

Rotary wing drones are equipped with motors and propellers. The main problem that drone designers are trying to solve is how to reduce the level of noise produced by propellers. For example, in 2018 researches from the Massachusetts Institute of Technology reported that they had developed a drone that takes advantage of a natural phenomenon known as ionic wind. This means that the propulsion system requires no moving parts, thus eliminating all noise. However, according to the developers, it is not clear whether the technology is viable and even if it should prove to be, it will likely take several decades to become economic (Ritter) .

An integral part of most modern drones is the camera. In addition, the newest models use GPS for navigation and have sensors that scan the surroundings and help avoid obstacles that could cause a collision. Some of the latest drones even have a feature that helps them avoid "no fly zones" set by the regulatory authorities (Corrigan).

Benefits and Uses

Today, drones have several applications owing to their unique capabilities and efficiency. They also have the potential to perform repetitive work activities, thus freeing up labor for more creative pursuits.

Among their most popular current applications are commercial aerial surveillance, filmmaking, disaster relief, real estate and construction, and recreational use. While drones that perform these activities do not have to fly substantial distances, they do require constant human supervision, which makes them more controllable and thus less prone to creating safety, privacy or noise issues, which are discussed in greater detail in part 1, section 3 of this paper.

And while there are other uses that pose greater risks to urban environments, the benefits to be had may outweigh the

costs. Owing to their nimbleness and maneuverability UAVs can deliver goods and materials to remote destinations and hard-to-reach places within cities, reducing the time as well as the cost of delivery. Even medications and medical instruments and supplies can be transported via drones, which could prove invaluable in emergency situations.

Over the past decade several companies have made significant efforts to promote the use of drones, including developing new prototypes, in addition to conceptualizing UAV landing pads and drone-adapted automated receiving units. Among the more futuristic but still possible uses involves the transportation of people. As noted in section 2.2, the first prototypes of a drone-car are already in development.

Among the first corporations to patent UAV-related technology was Amazon. The company has conceptualized first fulfillment centers as well as technology for collecting packages. However, lack of drone-related infrastructure as well as the high cost associated with constructing the requisite facilities means that some of the proposals won't be viable. For example, a patent filed by Amazon for a self-driving airship (Fig. 4) that hovers at high attitudes and carries drones that deliver packages to homes and businesses appears, at first glance, to be appealing. Among the advantages are its flexibility and low assembly cost compared to that of terrestrial fulfillment centers that need to be located at a relatively close distance to the customer base so as to provide full delivery service. However, at this stage in the conceptualization process, there is no clear understanding of how client and drone are to communicate. Moreover, it is envisioned that public amenities such as lampposts and power poles are to be used as package drop-off points (Fig. 5). This approach would, in many cases, rule out personalized delivery since not every house has its own street lamp. Second, the design of the drop-off points or delivery stations remains in the preliminary phase.

The ultimate goal for many of the companies working in this area is to integrate drones into civilian life. However, this

Figure 4. Amazon self-driving airship

Figure 5. Lamppost drop-off point

is not merely a technological challenge; it is also a matter of securing regulatory approval from the requisite authorities, given that current laws prohibit the use of UAVs within most of what constitutes urban airspace; and there is also the issue of public acceptance. The most important question, however, is whether society wants drones to be part of civilian airspace. The answer depends largely on whether the advantages of drones will outweigh the possible negative effects.

According to drone proponents, the integration of aerial vehicles into urban areas would not only reduce delivery times and shipment costs but would also reduce traffic congestion, given that the number of single-package deliveries would be minimized. Moreover, the capability of drones to facilitate critical public services, such as the previously mentioned disaster relief, makes this technology especially appealing.

2.2 Historical

Cities with skylines filled with soaring towers and fleets of aerial vehicles are often the backdrop to science fiction films and literature (Fig. 7-10). New York's Empire State Building, which opened its doors in 1931, represented the very first effort—experiment might be a more precise term—to adapt urban architecture to the concept of aerial transportation. A highly advanced building for the time, it was designed with a mooring mast for a spire that could serve to anchor the great airships of the day (Fig. 6). Even though following the Hindenburg disaster (1937), the mast was never used for its intended purpose, it still stands as a symbol for the new age of air travel (Bascomb).

Although it was the ancient world that first conceived of and attempted to develop a flying vehicle, the first manned-flight was accomplished with the aid of a hot air balloon in 1783 (La and Maas 193). This notable achievement provided the foundation for further efforts to enter airspace that culminated with the development of airships that entered commercial service in Germany late in the 19th century. The introduction in 1876 of the first petrol-powered internal combustion engine enabled the Wright brothers to achieve controlled flight for the first time. Moreover, in the first decade of the 20th century automobiles were evolving rapidly, and soon would be increasing people's mobility and changing the way cities were planned.

Figure 6. Empire State Building mooring mast

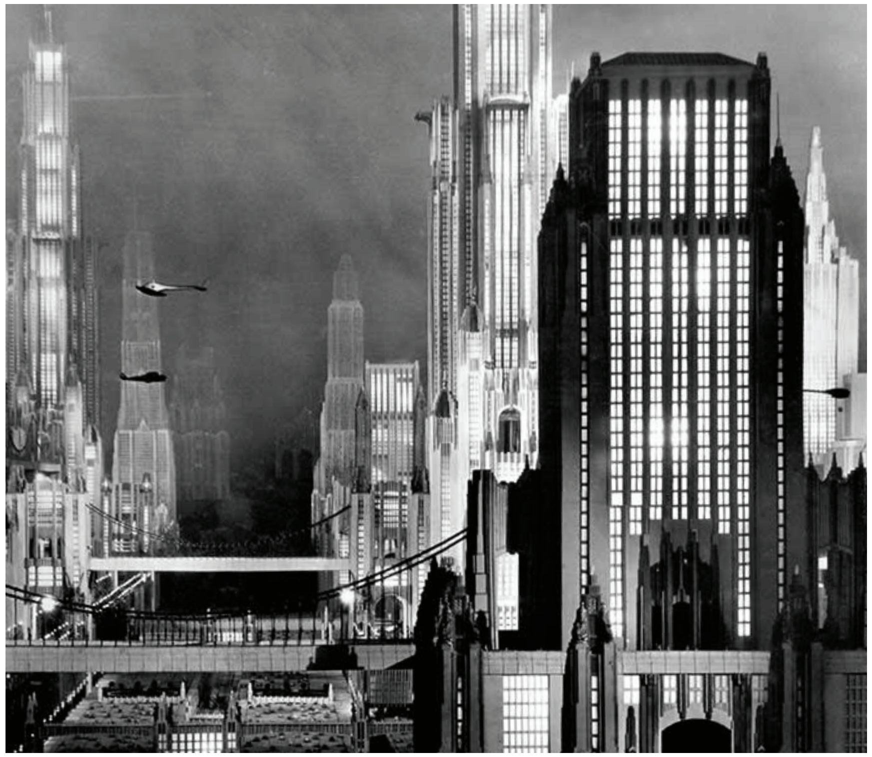


Figure 7. Just imagine (1930)

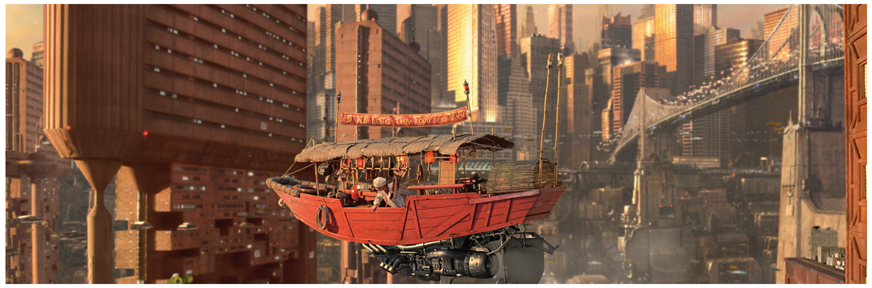


Figure 8. The fifth element (1997)

Figure 9. Star Wars (1977-2017)

Figure 10. Ready Player One (2018)

Although the airplane did not influence how cities were designed and developed at this time, efforts continued to develop a reliable flying machine that could operate within urban settings, thereby reducing traffic congestion.

Moulton Taylor (1912-1995) was an American aeronautical engineer and advocate of flying cars. He designed a vehicle called the Aerocar in 1949 that came very close to being mass-produced. Unfortunately, only six of his cars were built (Lert). Paul Moller (born 1936) is a Canadian engineer celebrated for his countless attempts to develop a personal vertical takeoff and landing car (Fig. 11). He devoted more than fifty years to this effort only to have a prototype fail due to its limited hovering capabilities (Kennedy). Currently, a number of transportation companies are developing flying machines of various types to transport people and goods. Many of these vehicles have demonstrated the ability to travel long distance carrying heavy payloads. Among the modern companies to seriously work on the concept of flying cars are Airbus and the Ehang Corporation, Chinese drone makers that developed "The Ehang 184" in 2014 (Fig.12). In addition, Uber is seriously working on the concept of flying taxi and has already identified potential markets for this technology.

While the dream of inventing new flying machines lives on, the forms aero vehicles take have changed radically. Today, the drone concept is viewed as one of the very few such ve-

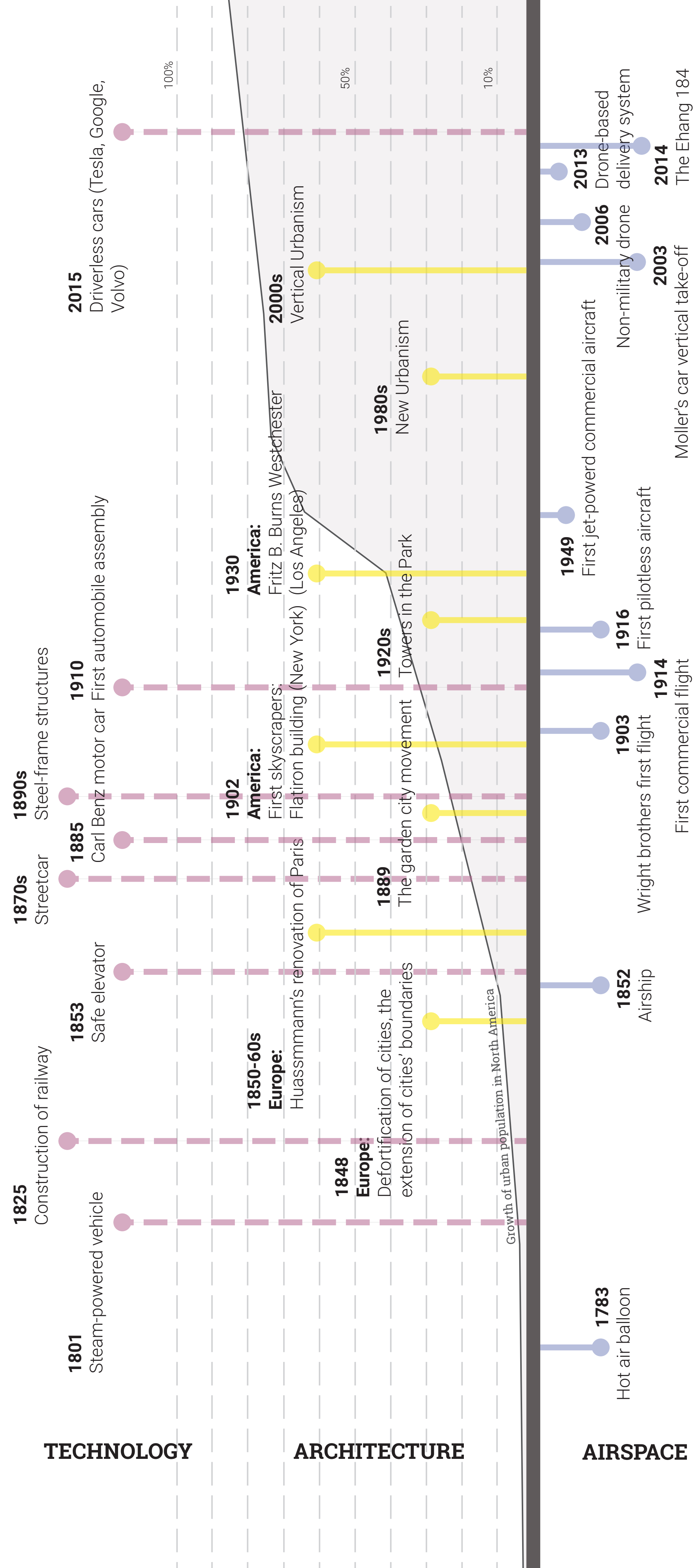


Figure 11. A magazine advertising Moller's Skycar

hicles capable of solving traffic congestion and other related urban problems due to its many technical advantages. The fundamental difference between drones and most other flying vehicles is that the former is capable of performing vertical takeoffs and landings. This essential characteristic eliminates the need for runways, which is especially important in the context of urban transportation needs. As a pilotless technology, moreover, drones eliminate the need for specialized pilot training and qualifications, thereby further reducing costs.

Figure 12. The Ehang 184

Despite all the predictions and efforts, flying vehicles remain absent from city skies. There are still too many obstacles to be overcome on the road to conquering the skies above urban centers. One thing is clear: the development of transport technologies has always influenced the way we live, and should drones ever prove economically viable and socially acceptable, they will undoubtedly affect urban dwellers in no small measure.

2.3 Urban

Urban Problems

Technological progress of the last two-and-a-half centuries has changed the way people work and live while enabling urban populations to grow exponentially, which, in turn, has created a host of urban problems.

In North America the rapid growth of the automobile industry at the turn of the 19th century was a major impetus to population redistribution and urban sprawl, resulting in the formation of highly suburbanized metropolises (Poston and Micklin 60). Residential areas began to shift outwards, forming new points of population concentration (Sridhar). The urban boundaries have been stretched over great distances, giving rise to a new form of urban development: the conurbation. These processes were inevitably accompanied by the construction of new transportation arteries to connect the nuclei of the poly-centric conurbation. This, in turn, led to ever greater traffic congestion and energy consumption, in addition to economic costs associated with the building of new infrastructure (Lin and Gámez 176).

Today, around 85 percent of major US metropolitan areas consist of suburbs (Cox). This makes commuting more costly and time-consuming and requires large investments in road infrastructure. For example, the US spends more than 30 billion dollars annually on national highway maintenance (La and Maas 36).

Despite the fact that aerial transportation is meant to improve the transportation system, the emergence of drones may have unpredictable impacts on the forms cities take. On one hand, drones can ease traffic congestion, thus reducing commuting times. On the other, they can increase suburbanization, thereby lengthening the distances between neighborhoods. Thus, two of the challenges that cities of drones will likely face lie in how to manage further urban growth and in deciding what model of city development to adopt—the concentrated vertical or dispersed poly-centric model.

Verticalization as a Response to Urban Failures

In order to try to envision in what direction UAVs will push the development of cities and what urban planning approach would be most appropriate, it is necessary to examine the proposals that have already been made to address the existing urban problems mentioned in the previous section. First of all, the problem of overpopulated sprawling cities with ever less mobility.

The growing negative impacts of constant urban population growth and urban sprawl provided the impetus for the development of fundamentally new models of urban settlement. This resulted in efforts to change the configuration of typical urban schemes and force cities to enter the third dimension instead of expanding ever more horizontally. This was supposed to allow for the formation of a more compact built environment that was more synergetic and efficient (Dean et al. 270).

Already during the Renaissance period architects had begun to envision the verticalization of urban environments. However, it was the beginning of the 20th century when the need to increase the densities of cities had become acute that architects began to embrace third dimension (Dean et al. 484). During this time many efforts were made to visualize the city as a concentrated, vertically connected structure with traffic incorporated into it. These efforts were to a great extent inspired by advances in technology such as the automatized elevator and steel frame construction.

An early vision of the vertical city can be found in The Cosmopolis of the Future by Moses King. These images produced in 1908 chronicle the transformation of New York city

(Fig. 14). The city is made up of aerial sidewalks and multiple layers of railway right of ways. The buildings are connected by bridges and pathways. The sky is filled with airplanes (Dean et al. 484).

In 1924 Ludwig Hilberseimer envisioned the city as a vertically expanded structure (Fig. 15). In being concentrated, it

Figure 14. The Cosmopolis of the Future, Moses King (1908)

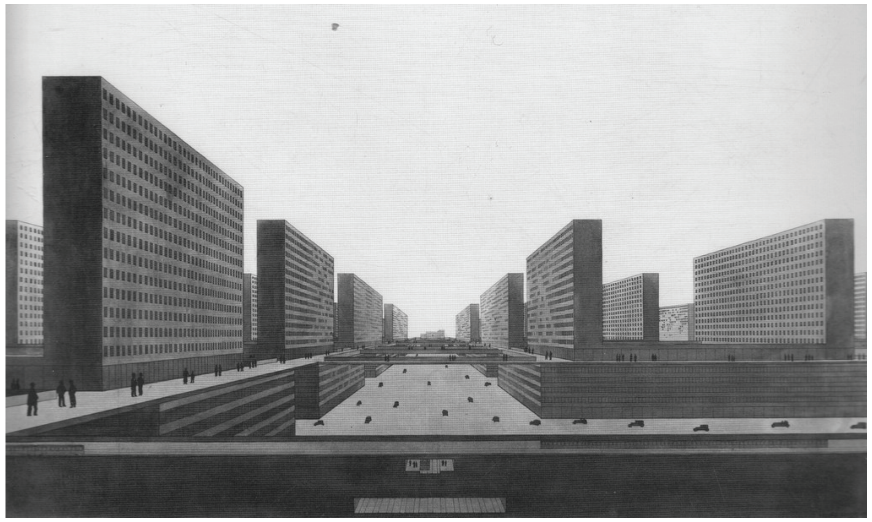


Figure 15. Vertical City, Ludwig Hilberseimer (1924)

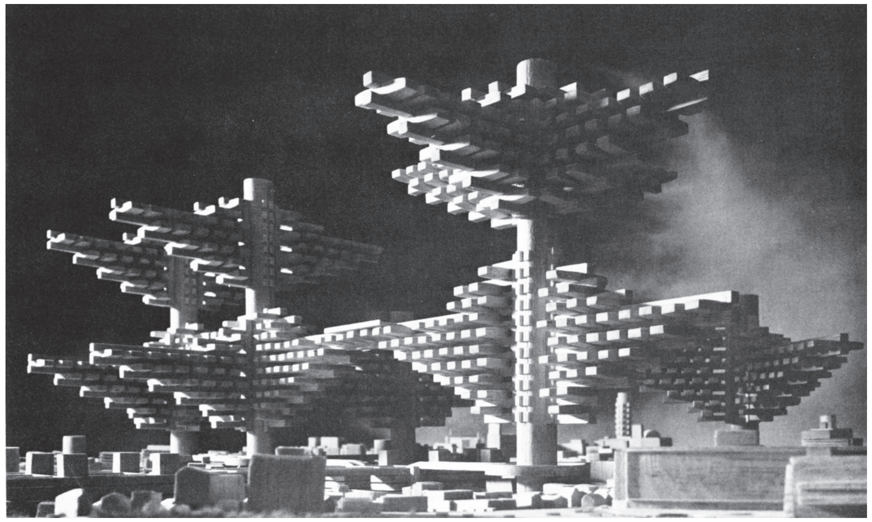


Figure 16. Clusters in the Air, Arata Isozaki (1962)

occupies a smaller footprint. The programs are linked vertically, meaning that everyone lives above their workplace (Dean et al. 486).

Le Corbusier's "City of Towers" and "Towers in the Park" concepts represented two of the first **"vertical city"** theories to address the challenges thrown up by the new urban forms. These static models still dominate urban planning in many countries.

Later examples include Arata Isozaki's Clusters in the air (Fig. 16). This is an attempt to maximize the use of urban space by developing buildings that feature stiff narrow vertical cores that like a tree trunk support multiple branches inside which the programs are located. The links between the buildings are all situated above ground, generating a network of spaces in the air (Dean et al. 490).

Although the interest in verticality was stimulated largely by the engineering innovations of that period (Hewitt and Graham 924), the rationale behind the numerous attempts at verticalizing the urban environment was its inherent potential to increase population densities (Dean et al. 484). This means that "when the population density reaches a critical point, verticality becomes an essential characteristic of a city" due to its capability to redistribute populations (Lin and Gámez 5). It is important to note that, in itself, increased density is not a factor that makes cities less livable; rather, it is a characteristic that promotes productivity and economic growth of the metropolis and leads to a much more programmatic diversity of the urban space (Dean et al. 271). However, population density is something that needs to be addressed and controlled so as to avoid unexpected consequences related to reduced mobility and the overall comfort of life. The urban planning that promotes the rational distribution of the urban environment's main components is crucial (Dean et al. 270). In the case of the phenomenon of suburbanization, the appearance of enormous peripheral zones was a natural response to the congestion occurring in the city center; but it is doubtful whether it was the most rational response.

One of the early urban design movements that promoted compactness as a solution was the **'new urbanism'** that arose in the United States as a response to the 'latitudinal' urban models predicated upon the automobile. The 'new urbanism' aimed to develop walkable, transit-oriented urban neighbourhoods (Lin and Gámez 5). A number of city districts in North America were developed on the bases of these ideas. However, the theory can be characterized partially as a failure as the new urbanist developments lacked urban peripheries, thus isolating the new districts from existing suburban neighborhoods.

The new urbanism was followed by the **'vertical urbanism'** model that emerged as an alternative approach to densifying cities and extensive urbanization, offering its own vision for designing compact cities. This concept "addresses the city as a multilayered and multidimensional organism" (Lin and Gámez 11). Its advocates claim that the essential difference between how the traditional skyscraper is designed and 'vertical urbanism' lies in a greater functionalism, characterized by increased connectivity and an interactive environment spread across multiple layers of the urban fabric (Lin and Gámez 11). In other words, the metropolis becomes a three-dimensional spatial network where different programmatic urban elements are connected not only through the ground-level landscape but the multiple threads stretching between different components of the built environment. The connecting threads can take the form of spaces wherein people mingle, such as parks, plazas and shops, or vehicular arteries, sky-walking corridors or even aerial highways that would allow for a radically new form of communication in a city.

Projects like the High Line park in New York City (Fig. 17) and the Coulée verte René-Dumont park in Paris (Fig. 18) pro-

Figure 17. High Line park, New York

Figure 18. Coulée verte René-Dumont park, Paris

vide examples of how the interconnectivity of urban elements can drive the evolution of cities and contribute to eliminating urban decay by adding functional connections between different parts of neighborhoods. With the introduction of connecting arteries, these areas have become more vibrant and attractive both for the public and developers (Lin and Gámez 11).

Another example is the Zaha Hadid's Galaxy Soho project (Fig. 19), which is a mix-use development occupying an entire city block in Beijing. A distinctive feature of the building is its varied and dynamic interconnecting elements, such as bridges and platforms, that link the upper levels. The building consists of four massive shapes that engage with each other, forming a continuous interior space. This is an example of how independent urban built forms can be designed as a holistic organism that combines different functions.

According to 'vertical urbanism' theory all connecting elements, regardless of their form are usually parts of a circulation system that aims to link programmatic volumes such that they are no longer dead ends in a building but rather part of a flow that merges into the next logically and spatially appropriate programmatic unit (Lin and Gámez 13).

The notion of 'connections' that the theory actively promotes should not be taken literally or imagined merely as a

Figure 19. Galaxy Soho, Beijing

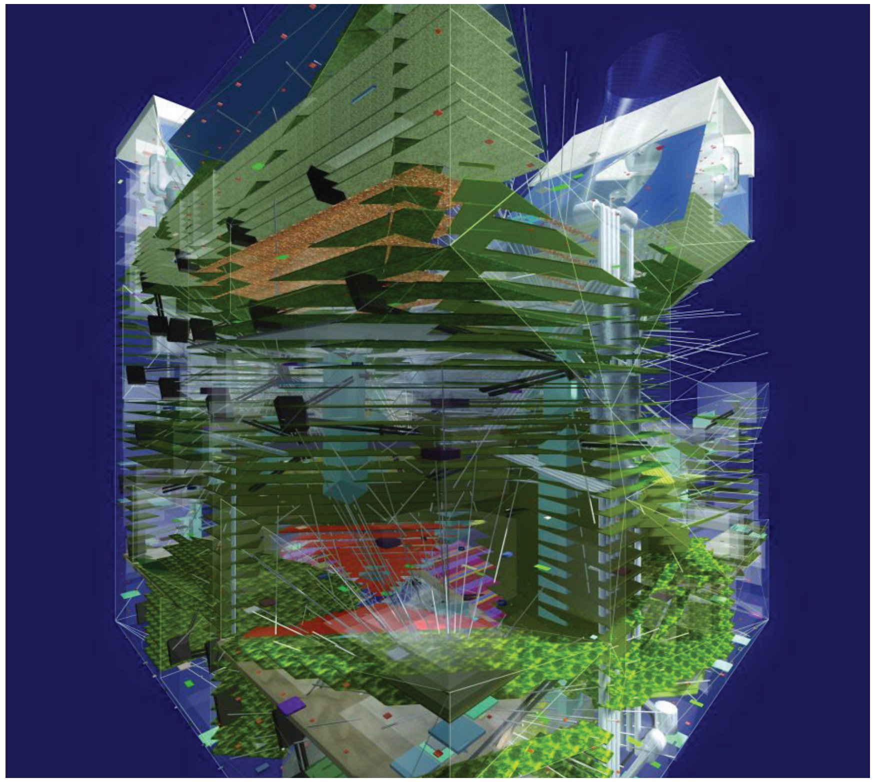


Figure 20. 3D City, MVRDV

complex of monumental physical structures binding together a city, although this may appear to be the case. It seems that 'vertical urbanism' conceptualizes a city as a system, the different element of which are stitched together using adapted building typologies that play not the least important role in connecting the points between different urban constituents. Although each site would require the development of a unique tool set appropriate to the context, this approach can be another way to establish interconnections.

Developed by MVRDV in the 2000s, **'3D urbanism'** is another utopian urban theory that seeks to address the "overwhelming process of global space consumption" (Dean et al. 270), i.e., the twin processes of urbanization and the uncontrollable growth of cities. Similar to 'vertical urbanism', it aims to increase the potential of the city by stepping beyond two-dimensional arrangements and organizing cities in a more compact manner (Dean et al. 271). Another intent here is to increase densities. This model was initially conceived as a utopian adaptation of the 3D cube that conceptualizes the city as a compact box containing all the resources and amenities required of a spatially rich city. (Dean et al. 280) (Fig. 20). The concept aims to minimize the need for cars and promote the use of alternative transport types, thereby reducing the need for massive infrastructure (Dean et al. 418). This theory arose in concert with the concept of a 'skycar' city developed by MVRDV that aimed to increase the potential of three-dimensional cities (La and Maas 24).

KM3 published by MVRDV in 2004 maps out all phases and components of their research pertaining to density as it relates to contemporary life and architecture. This work summarizes the histories of all the vertical urban theories, including the most fantastic, while providing a new formula for building modern cities. The authors use an incremental approach, offering examples of projects that address, intentionally or arbitrarily, the myriad issues relating to runaway urban growth and technological change.

The authors pose five critical questions:

- "How can we organize this three-dimensional world?" (La and Maas 271)

- "How can we live or, as some might say, how can we survive, in this third dimension?" (La and Maas 271)

- "How is its construction to be financed?" (La and Maas 271)

- "What kind of logic leads inexorably to this kind of city? With what tools can we create it?" (La and Maas 271)

- "And what kind of infrastructure is required?" (La and Maas 271)

Many of the examples of 3D urbanism that KM3 provides have to do with massive changes to infrastructure such as altering transportation routes by elevating them above the

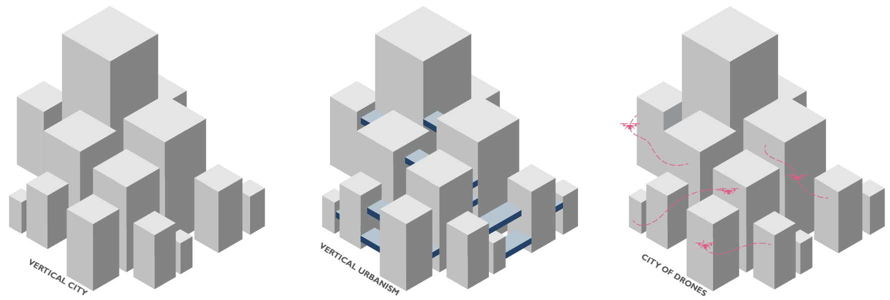


Figure 21. Evolution of the urbanism

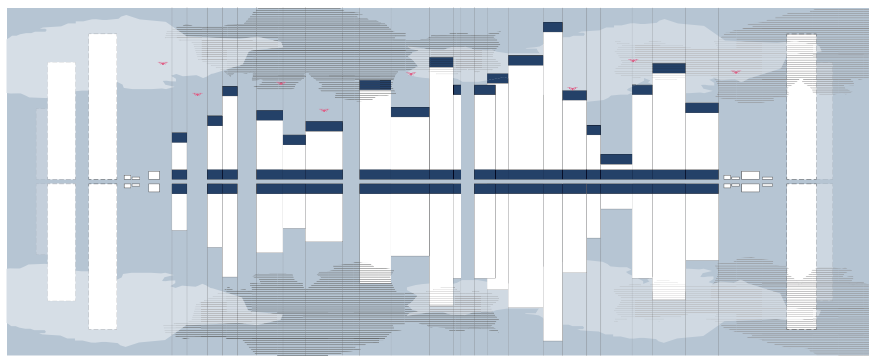


Figure 22. Programmatic flip

ground plane.

The projects use different strategies to reorganize the built environment with a view to creating a city that is a three-dimensional mesh filled with vertically stacked objects that are living spaces, working spaces, and landscapes—everything that constitutes a city. These projects exploit all the inherent capabilities of verticality to spatially redistribute programs and allow for densification, making the most out of limited space (Dean et al. 340).

One of the examples featured here is Stacked Landscapes, the Dutch pavilion built for the 2000 World Expo. The authors describe it as "nature arranged on many levels" (Dean et al. 340).

In the new millennium, the appearance in any city of great fleets of drones would be no more fantastic than that of hosts of cars at the birth of the 20th century. Should it ever happen that unmanned aerial vehicles come to fill the urban

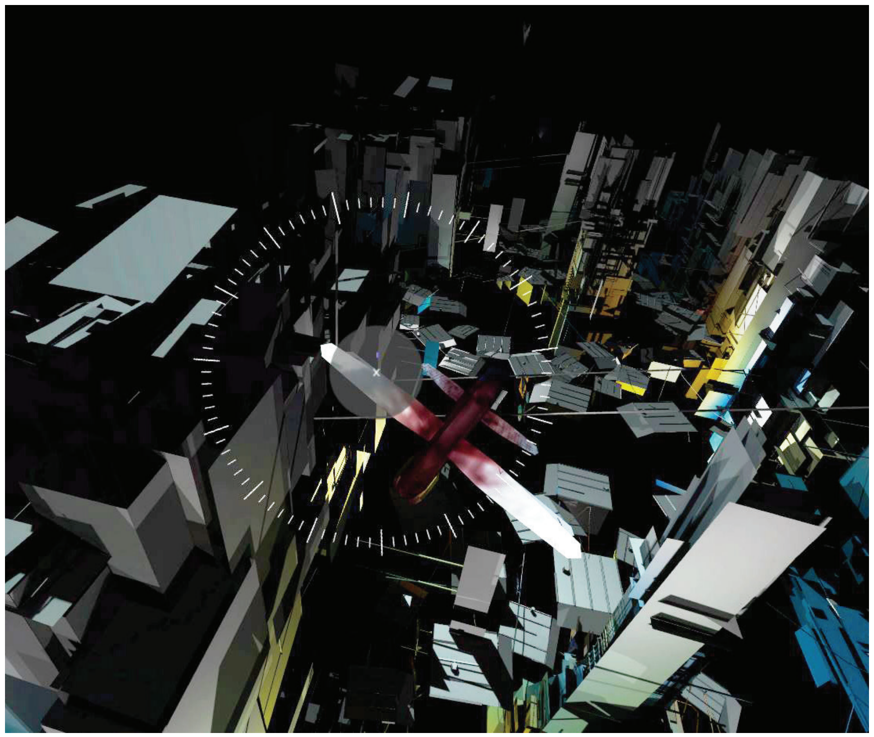


Figure 23. City of Drones, Liam Young

skies, the new 3D Urbanism will have arrived, for better or for worse. And rather than large-scale concrete infrastructure such as elevated transit systems, it is the drone that will bind together cities (Fig. 21).

What is the Value of Verticality in a City of Drones

When thinking about a world in which drones are commonplace, one imagines multilayered, aerial highways filled with swarms of flying robots that dominate city skies. The speculative architect Liam Young, who is a passionate advocate of drone technology, has created a drone-based art installation in the form of a digital landscape where an apparently infinitely large city can be explored through the camera of a drone (Fig. 23). This is a spatial system that consists of an endless vertical environment wherein drones are integral elements. The flying machines move far and wide in all directions binding the city together. Young's installation demonstrates how much more agile and efficient drones are as compared to clumsy ground transport. The main urban scene is the infinite airspace that provides unlimited opportunities for development as well as a sense of vastness.

The interrelationship between unmanned aerial vehicles and verticality becomes clearer as we start thinking about the essence of drones and about the role they play in our lives. One of the dominant drivers behind the concept of a city of drones is the potential of UAVs to reduce the number of commuting trips. The mobility these vehicles provide seems enormous compared to that of conventional transportation systems. However, to unlock the full potential of UAVs, it is necessary to create urban settings that allow for transport flows across multiple levels, thereby reducing the congestion of commuting pathways and in the process speeding up traffic flows. Verticalization and compactness will play important roles in making drone transportation more efficient as will the shorter travel distances they enable.

In dividing the urban environment into multiple flying corridors and elevating many of our quotidian life activities off the ground, flying robots will shape the city's growth and transform it in significant ways. This means that the built environment will have to conform to the needs of drones. When thinking of the drone as a substitute for the automobile, it is worth noting that commuting and transportation patterns as well as infrastructure will need to be altered to meet the needs of aerial transport.

For this reason, drones may provide the greatest benefits if integrated into urban planning models that support 3dsness and compactness. The main principles of vertical urbanism will ensure a dynamic relationship between compactly organized programmatic elements within the vertically grown urban environment, providing drones with an environment that will allow for shorter more fuel-efficient commuting trips. First, it will retain the connections between transportation arteries and the buildings' programmatic components. This means that the vertical span, or in other words the height of the urban built environment, will be adequate to accommodate the requisite density of intra-city traffic, making it possible to travel directly to that level of a building one wishes to access. The precise height deemed necessary will vary from city to city and will depend mostly on the scale of the urban area and population density. This will minimize the need to move along the vertical axis of a city in order to access that specific "travel corridor" that will provide the most efficient routing. All this will be a part of zoning strategies to be discussed in the next section.

Zoning and air traffic management

Prior to discussing alternatives to the typologies of urban buildings that are suitable for drone transport, it is necessary to understand what technologies can facilitate the integration of air traffic into urban environment and how the traffic will be managed. What are the limitations of drone operations in a

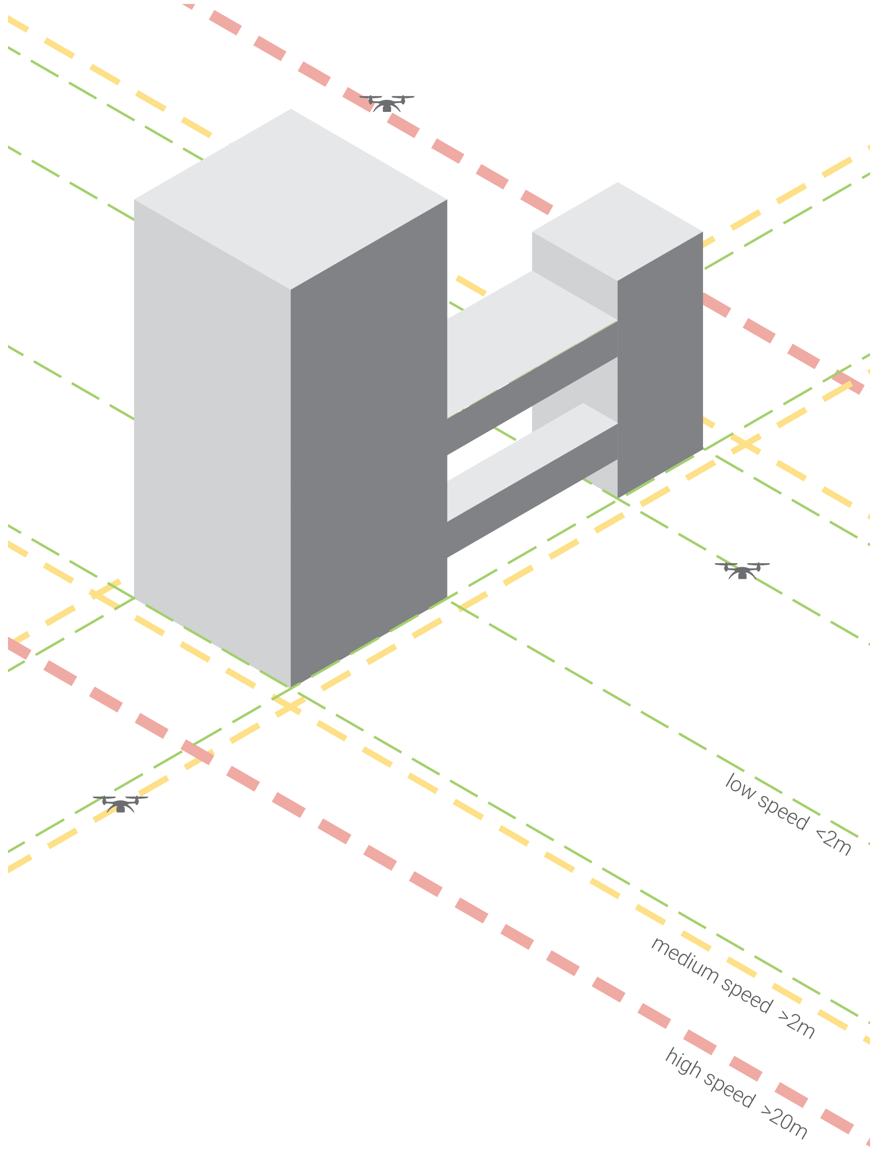


Figure 24. Zoning

city? Would it be necessary to divide cities into zones?

The primary concern that zoning must address has to do with ensuring the safe and efficient operation of aerial transportation technology. Establishing zones and traffic rules for UAVs will minimize disruptions to the everyday activities of people while greatly facilitating the delivery of goods and people.

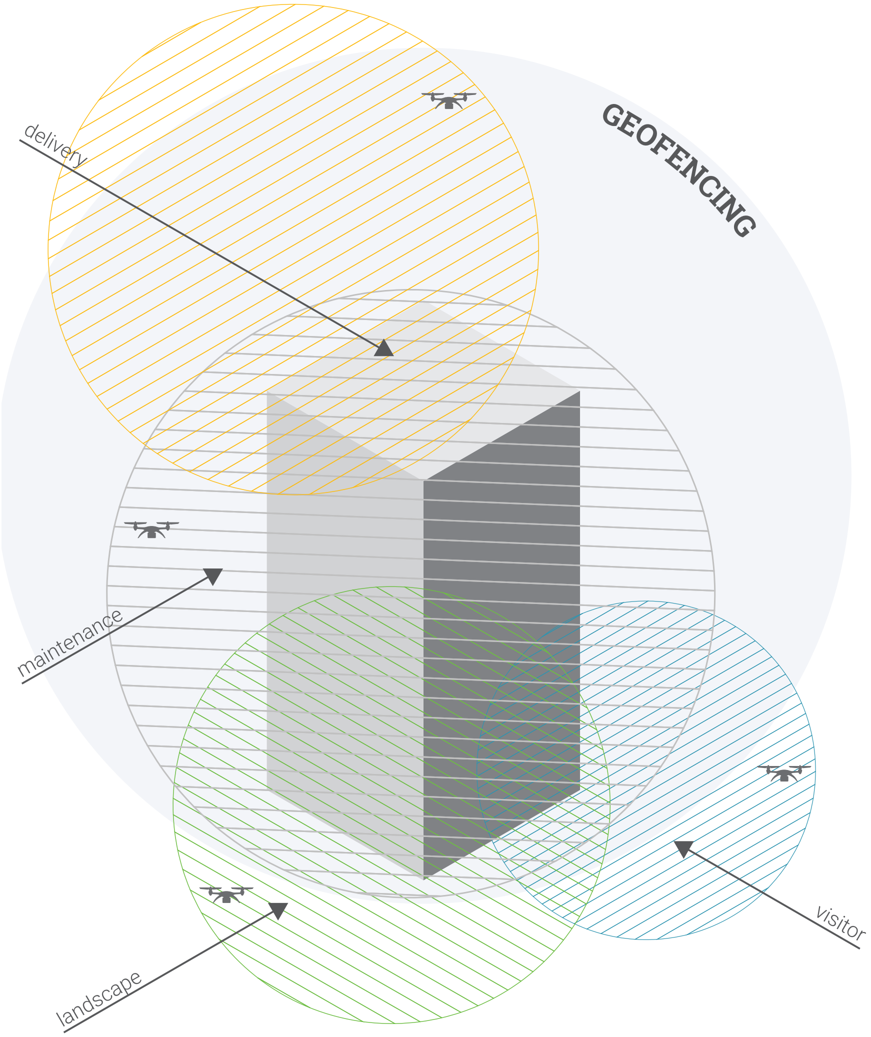


Figure 25. Geofencing

First, it would make sense to divide UAVs into two major categories: drones that operate within urban limits at low altitudes and those that fly longer distances at higher altitudes. While this paper focuses mainly on the former, the latter should not be ignored completely as intercity transport might also impact inner-city traffic. Second, it is worth noting that, despite the greater safety and privacy provided by zones, it would not be practical to completely isolate UAVs from the built environment. The reason is that in order to serve a building a drone needs at least one access point in close proximity

to or located on the building, and likely multiple access points if it performs work related to the maintenance of the building.

Dividing a city into zones on the basis of altitude, speed, time spent in the zone, time of day, and number of drones flying in a single zone at a given time may allow for maximum control of the airspace (Fig. 24), for example, as when the speed and number of drones in a zone is directly proportional to the distance from a residential high-rise. The distances may vary depending on the building program. This approach would minimize the negative impacts associated with noise; however, at same time, it would reduce privacy, given that slow flying drones can capture more data than high speed UAVs. This means that the public would be faced with vari-

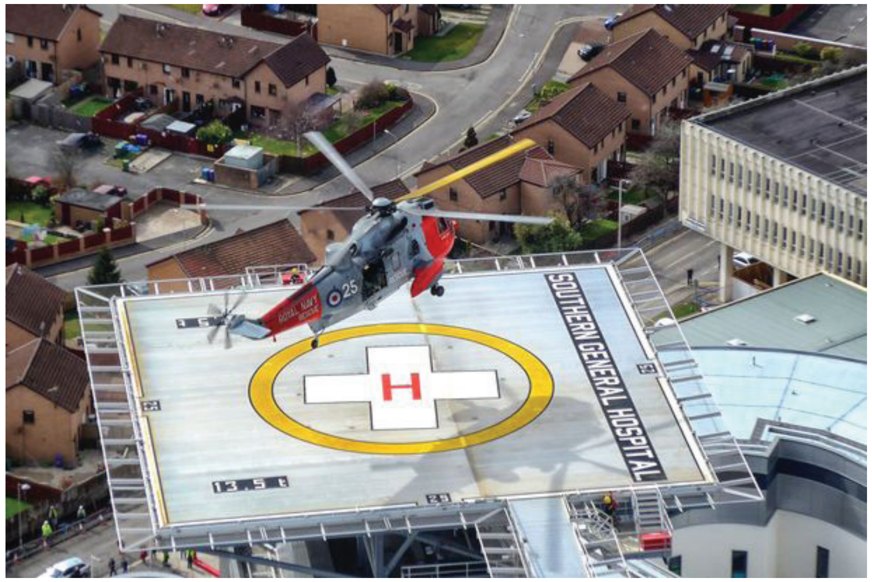


Figure 26. Helipad

ous trade-offs, for instance, between the comfort level desired and the service a UAV can provide. It would be problematic to prevent drones from flying close to private and semi-private zones, as this would limit their potential to provide personalized services. Isolating drones from people would require an additional 'connecting' mechanism to bridge the gap between customer and drone that may reduce efficiency, thereby contradicting the whole point of employing drones in the first place.

One effective approach to demarcating zones is geofencing, a system already being used to manage air traffic and to keep unauthorized drones from entering a restricted space (Hermand et al.). Geofencing uses GPS technology to create a virtual perimeter. It can specify what zones drones are allowed to enter and how close they can approach a given building, as well as what drones can enter the building (Fig. 25). For example, a delivery drone would be allowed to approach a mailroom or a 'delivery post' but not a public space, such as a lobby, corridor or patio.

While geofencing can ensure that spaces around buildings are protected and circulating traffic regulated, it might not be necessary for guiding drone flows outside this kind of regulated space by forcing them to follow certain flight paths. Geofencing would still guarantee that no drone entered a restricted area or exceeded the speed limit, but the drone would have a right to choose the most efficient route to its destination. The traffic would appear chaotic to the human eye, but not to the drone, because it is able to communicate constantly with other aerial vehicles and negotiate a flight path. Unlike humans, drones can anticipate danger well ahead and take appropriate action to avoid it.

Unlike helicopters operated by humans, drones do not require any visual identifiers or signs to guide them where to go or where to land. All they need are wi-fi or Bluetooth beacons that allow them to navigate through space (Fig. 26).

Viewing Perspective

Until recently an aerial view had little aesthetic appeal, despite being one of the most important tools used in urban design and one of the essential constituents of every architectural and city planning project. One possible reason is that modern aircraft fly at high altitudes, precluding sightseeing.

Drones, however, offer us an opportunity to view the world from varying altitudes, and in a radically new way. They allow us to reach places that otherwise we would never reach and to comprehend the surrounding environment in a different way. The emergence of this technology has forced us to rethink the importance of the fifth elevation as a new way to observe the physical environment. This will be evident in many aspects of a transformed built environment, starting with the way we access our surroundings and ending with how we socialize and interact with one another.

Norman Foster asserts, "the reality of our existence is at the ground level and the perception is at the ground level, but you certainly do see the big picture from above and do see the fifth elevation. The experience of flight is to heighten the sense of awareness" ("Elevation"). As in the case of his Apple Park project (Fig. 27), the corporate headquarters of Apple, most of the existing photographs of the building are taken from the air because it would not be possible to perceive this

Figure 27. Apple Park, Norman Foster

structure in its entirety from the ground level. “It was almost designed to be seen from above” (“Elevation”). Indeed, it would be difficult to comprehend the monumentality and the design idea of this building from a ground perspective. If one were to view a photograph of Apple Park taken from the ground, it

3. SOCIETAL IMPACTS

3.1 Privacy

Over the past few decades technological advances have come to threaten the traditional notion of privacy. The use of surveillance systems to monitor human activities has fueled concerns that 'Big Brother' is watching us all. And though the right to privacy has always been guaranteed in democratic societies, state surveillance appears to be encroaching upon this right. The appearance of cameras and other advanced monitoring tools, including drones, has elevated state surveillance to a new level. Drones may be viewed as a modern day 'panopticon' due to their potential pervasiveness and invasiveness. Moreover, while the original 'panopticon' (Fig. 28) may be considered a static means of surveillance, drones are dynamic owing to their maneuverability.

In a short film entitled Robot Skies architect Liam Young shows what the world looks like through the camera lens of a drone engaged in state surveillance (Fig. 29). It flies across residential neighborhoods, recording and analyzing every activity within camera range, including what is happening within homes. It can identify individuals and access personal information about them from government databases. The film reveals a dystopian reality where very few activities can remain private.

The vertical expansion of the urban environment by unmanned flying vehicles will drastically alter traditional notions of individual privacy and ownership. Their ability to fly at high altitudes and carry cameras, along with their agility and cost effectiveness, makes UAVs an excellent tool for surveillance (Schlag). They also enable individuals to monitor the activities of neighbours. Presently, in North America UAVs are

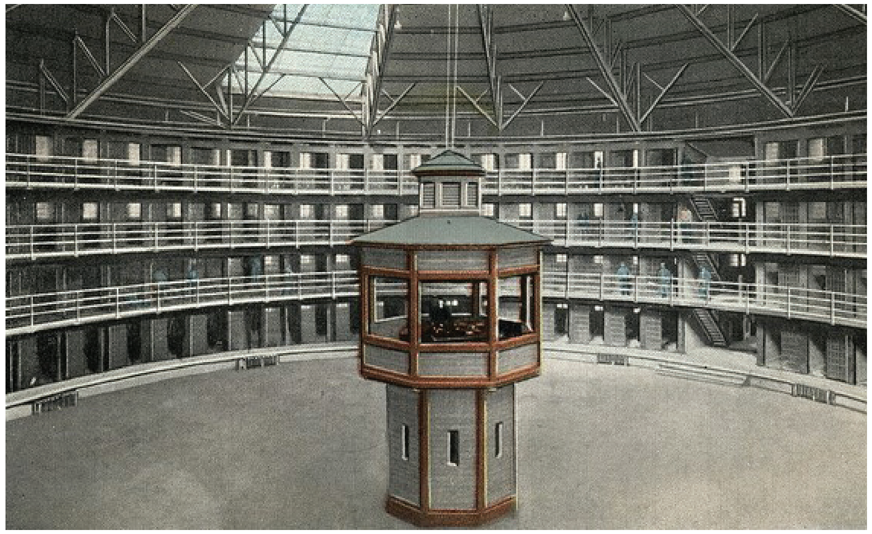


Figure 28. Panopticon

Figure 29. In the robot skies (2016)

strictly regulated to ensure that the individuals' privacy is not violated. The current set of rules prohibits drones from flying over private property and taking photographs by regulating the distances drones can fly from people and buildings ("Flying Your Drone"). However, should drones come to populate the skies, it is likely that the existing laws will be difficult to enforce. The full integration of drones into the urban environment and their efficient utilization will likely require that privacy and other laws and regulations be 'liberalized'. This will make it easy for unauthorized individuals to invade virtually anyone's privacy merely by flying a drone over his/her property. This problem will be exacerbated if UAVs become omnipresent, and thus no longer the object of attention. Amidst a swarm of other flying machines, a lone 'rogue' drone will likely go unnoticed. This potential threat will grow as computer technologies evolve and drones become vulnerable to cyber-attacks. The video footage and other information stored in UAVs may become a target and, consequently, fall into the wrong hands.

Apart from their ability to collect and store information there are other ways in which UAVs can shift the boundary between private and public. A drone landing in front of an apartment alters the traditional notion of a building's access area by conflating public and private zones. While locating a landing pad adjacent to one's high-rise apartment may be convenient, this would likely invade the privacy of one's neighbours and otherwise disrupt their lives.

This raises the question of how to protect individual privacy in a drone-ridden city. While it is unlikely that the problem of software attacks can be managed by architectural innovations, that of blurred boundaries between the public and private spheres could potentially be addressed by certain typological and configurational changes.

Figure 30. Balconies - landing pads

Many scenarios of how drone-friendly residential towers might be structured show buildings that feature landing pads incorporated into large balconies attached to their façades (Fig. 30). While this typology seems relatively simple and efficient, it does not take into account many of the societal impacts that arise with the widespread use of drones.

In a traditional North American high-rise building the problem of privacy is often related to the short distances between neighbouring towers. Zoning regulations do not always protect privacy, and in the absence of architectural solutions, residents may find their privacy violated. In a city of drones an additional layer of protection is required to address this problem.

3.2 Noise Pollution

In addition to invading the individual's privacy, drones can create excessive noise. Even though technological improvements are likely to reduce noise levels, this will be offset by the growing volume of aerial traffic. Part of the solution lies in establishing strictly regulated flight zones to ensure public safety and reduce noise levels. For example, according to some studies, regulating flight altitudes could alleviate considerably the issue of drone noise. Relatively small changes in this respect can have a greater effect on abating noise pollution than reducing the number of UAVs on the aerial highway (Lohn 21).

As in the case of breaching privacy, the most vulnerable areas of a building with respect to excessive noise levels are windows, balconies and outdoor public spaces. The architectural solutions for mitigating threats to privacy can also address problems related to noise from drones. Shielding a building's occupants from intrusive noise may require developing radically new typologies that would provide additional "barriers" for screening out noise.

3.3 Social Hierarchy

The phenomenon of social hierarchy is reflected in many aspects of urban life. It can be present anywhere within the metropolis, though the scale may differ. It may segregate people into wealthier and poorer neighborhoods, but it can also be seen within the interior of almost every high-rise building. While hierarchy is more obvious across the horizontal plane of urban landscapes, it is also clearly evident across the vertical plane. The problem stems from the typology of contemporary skyscrapers that often suggests the absence of a dynamic relationship between different programmatic elements of the buildings, which in turn, may become the means for establishing social hierarchy. Especially in big cities, floor space is positively related to property prices (La and Maas). The factors that determine the price of an apartment include, among other things, the view, the noise level, the amount of daylight to be had, and privacy, meaning that residents who occupy the higher floors are further removed from the urban bustle and pay for the privilege in terms of higher rents. Apart form the noise level, all these factors have a positive relationship with the apartment's distance from ground level and rental price. Thus, penthouse and upper floor apartments usually mark the high social status and affluence of those who occupy them.

The introduction of drones may mean that the living experience across all floors of an apartment building will be equalized, as the activities that usually occur exclusively at ground level will be redistributed across the urban vertical plane. This means assumptions about the ground plane and verticality long held by architects might begin to change. In future, upward movement may not allow one to escape the urban bustle; indeed, those occupying the upper floors of high-rise buildings may become more vulnerable to it.

4. PROPOSAL

4.1 The Project

The aim of the proposed project is to envision a sky station prototype that would rest atop a building. In creating a third urban dimension, this kind of infrastructure can improve accessibility to the urban core as well as enable higher population by means other than massive physical links becoming a connector between the skies and the ground.

The prototype would be capable of accommodating passenger drones and providing direct access to existing ground and underground transportation systems. All these components would be designed to operate as a single integrated system.

Instead of extending the existing terrestrial transportation system, an urban network of flight corridors will be established, along which drones would travel, connecting sky stations scattered across the city (Fig. 31).

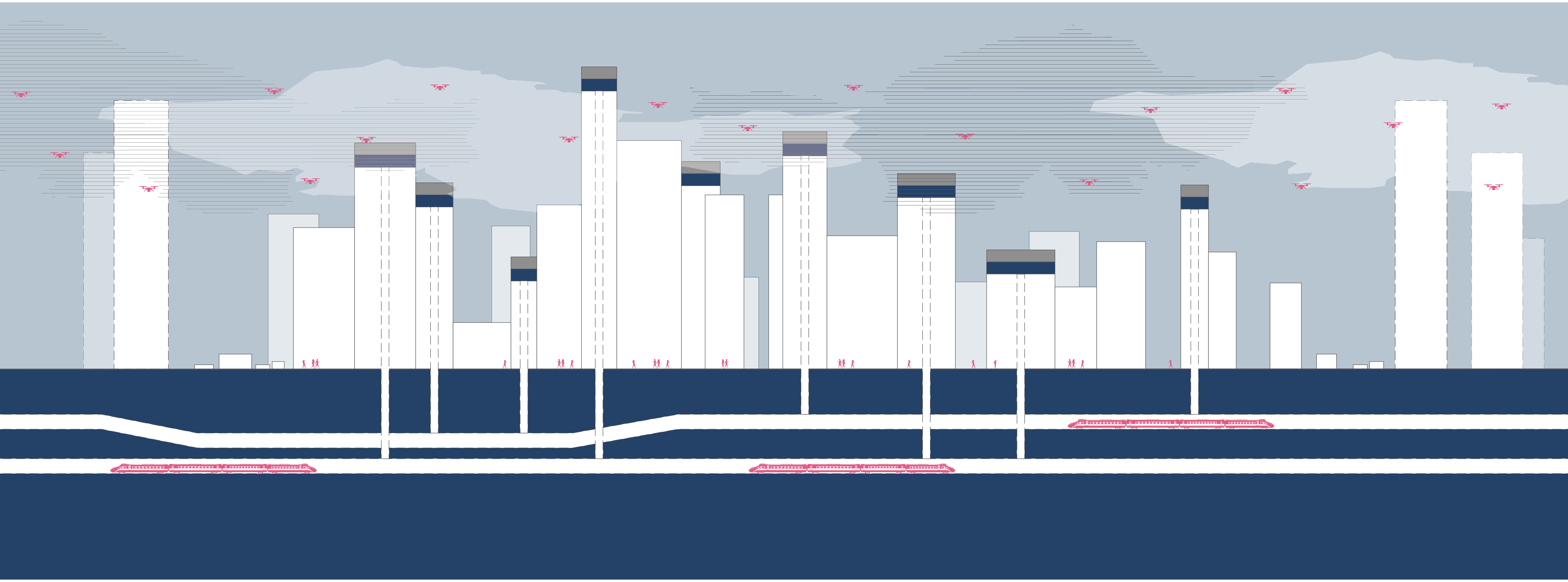


Figure 31. Drone enabled 3D urbanism

4.2 Possible areas of intervention

Typology

One of the main objective will be to reimagine the old typology of the building, adapting it to the use of unmanned aerial vehicles.

The study of building typologies was initiated by developing generic diagrams that depict possible types of drone adapted landing facilities (Fig. 32). In particular, where and how to integrate takeoff and landing pads for transporting people will be emphasized. The study aims to examine the advantages and disadvantages of each typology and find the optimum solution.

Configuration

The way we orient buildings or landing facilities within urban environments may be affected as well. In case of residential developments the orientation of landing facilities can play a key role in determining the level of privacy a given space can provide. The amount of vulnerable façade surfaces, such as glazed and open areas, as well as noise protection may depend on how a building and landing facilities are oriented in relation to the heaviest drone volumes.

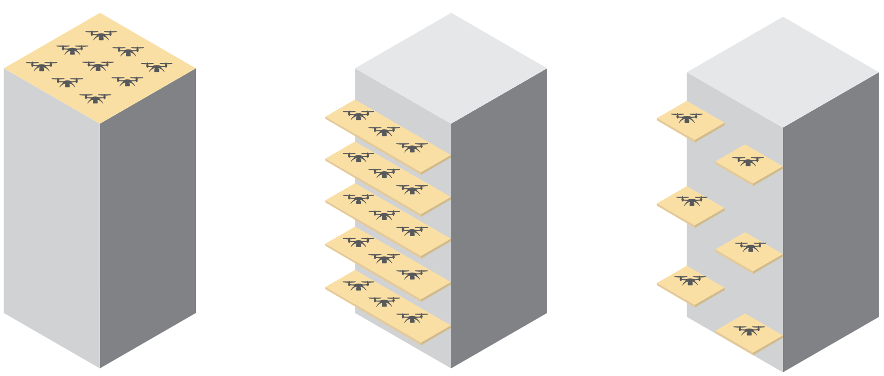


Figure 32. Typologies

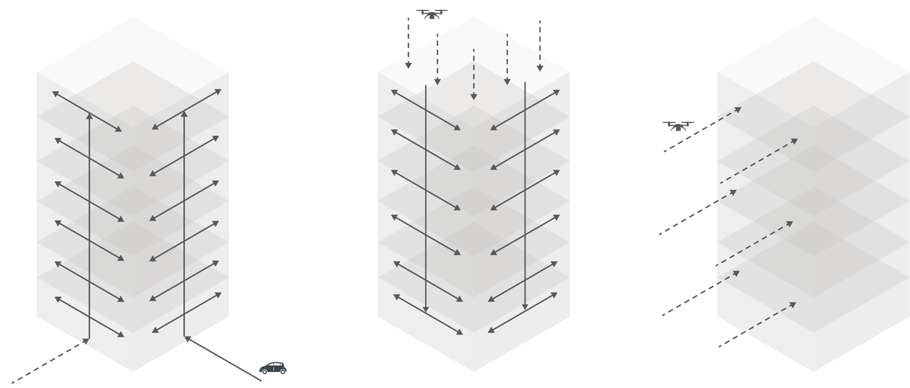


Figure 33. Circulation / Access

Circulation

To maximize the efficiency of transportation drones, certain changes to typical circulation patterns within buildings will be necessary, which in turn will likely lead to major changes to the built environment. These changes will affect access zones and public spaces as these areas are located at the interface between exterior and interior elements, serving as a buffer between the environment in which we travel and that in which we live (Fig. 33).

Access

While in current urban settings entrance and supply zones gravitate to ground level to provide access to the building(s) closest to land transportation routes, in a city where most of the commuting trips are made by aerial vehicles, access zones would be relocated to higher levels to accommodate the direct connection of transport and programmatic volumes (Fig. 33).

Public Space

The use of a three-dimensional framework will result in the redistribution of public spaces across vertical levels. However, the way people use and access public spaces may change dramatically. Locating spaces within vertical networks that combine the functions of public spaces and connecting pathways may enhance the social quality of these spaces by offering a greater variety of uses.

4. SELECTION OF SITE AND BUILDING

Los Angeles was selected as the site for the proposed study because the city conforms to a programmatically diverse urban development model that features the kinds of conditions and challenges that might test the capabilities of drone technology.

Los Angeles is by far one of the most suburbanized megalopolises in the world. Greater Los Angeles consists of several suburban regions that lie at a considerable distance from the urban core center. The urban model of Los Angeles can be characterized as horizontal urbanism. The metropolitan area, according to the United States Census Bureau, is dispersed across more than eighty thousand square meters, making it the largest metropolitan region in the US in land area. The city also has many of the “indicators” common to sprawling cities. One of the most visible of these is reduced accessibility due to dispersed poly-centric urban development (Haughton and Hunter 80). Starting from the 1960s most of the city’s growth

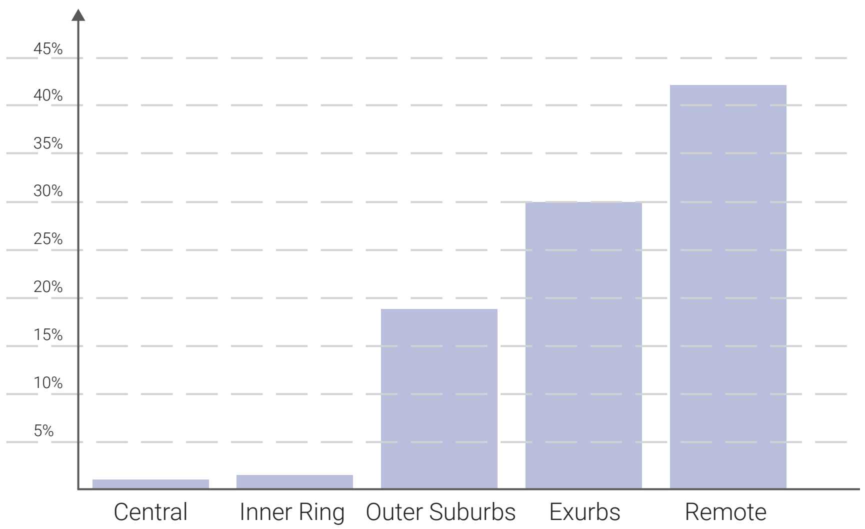


Figure 34. Los Angeles population growth

was suburban with low-rise development the dominant built form. During the period of deindustrialization in the 1970s when most of the industries moved out of the city center, the decline of the inner-city was accompanied by the growth of the suburbs (Fig. 34). As a result, central Los Angeles began to decay rapidly, making it undesirable for residential living (Ewing). Following this restructuration, the city was labeled a ‘donut’ city due to its massive peripheral expansion and underpopulated central core.

Today, downtown Los Angeles is rapidly recovering from urban decay as new development comes on stream, including massive public transportation projects, such as major extension to the subway system. Yet the downtown area was and remains underpopulated and difficult to access from the suburbs. The downtown hosts predominantly office space. There is a long-term need for additional residential developments (“Downtown Los Angeles”), meaning that this area would benefit from programmatic and spatial diversification as prescribed by the concept of the compact city.

One of Los Angeles’ major urban problems is massive traffic congestion— among the worst in the world (“Los Angeles”). Despite the city’s extensive network of intra-city rail transit, the automobile remains the dominant mode of transportation since compact, walkable, transit-oriented development is limited. This situation is exacerbated by the fact that the suburbs consist of large private land holdings that promote segregation of land uses (Ewing 109).

Los Angeles could benefit from drone technology that can reduce the length of commuting times and relieve traffic congestion. However, this is not merely a problem of amending regulations; it is a question of how to guide further growth so as not to encourage urban sprawl, of how not to allow drones to trigger peripheral expansion as automobiles did several decades ago. All these challenges make Los Angeles an exciting place to test new approaches to urban development.

The area of Los Angeles where the site is to be located will have to be plagued by traffic congestion and pollution. Lack of parking spaces and public places as well as programmatic connectivity with the surrounding context are factors to be considered when choosing a specific spot.

The Bank of America office tower (Fig. 35) was selected for the proposed project because the building and its location both conform to a type of development that features the necessary kinds of conditions listed above.

Figure 35. The Bank of America Plaza

6. DESIGN

6.1 Flight Corridors for Drones

Most modern drones feature reliable obstacle avoidance and navigation systems. However, assuming a growing volume of air traffic, additional safety measures, including regulations and protocols, would be required.

For example, different speed limits and altitudes might be assigned to specific flight corridors (Fig. 36) situated above the buildings. Imagine a three-dimensional grid consisting of three types of corridors; a high-speed, high-altitude corridor (in pink) for drones flying long distances; a low-speed, mid-altitude corridor (in blue) for drones descending or climbing; and a low-speed, low-altitude corridor (in grey) wherein drones can fly with no restrictions.

Flight corridors would not increase flight times as some might think. What they would do is help organize traffic and possibly enhance the operation of automated obstacle avoidance systems. Moreover, the horizontal intervals separating flight corridors might vary across space. For example, in downtown cores they might be 500 meters, whereas in the suburbs they might be increased or decreased to allow for more efficient routing. Drones in high-speed corridors might be allowed to cut corners so as to avoid having to reduce speed in order to make a 90-degree turn (Fig. 37).

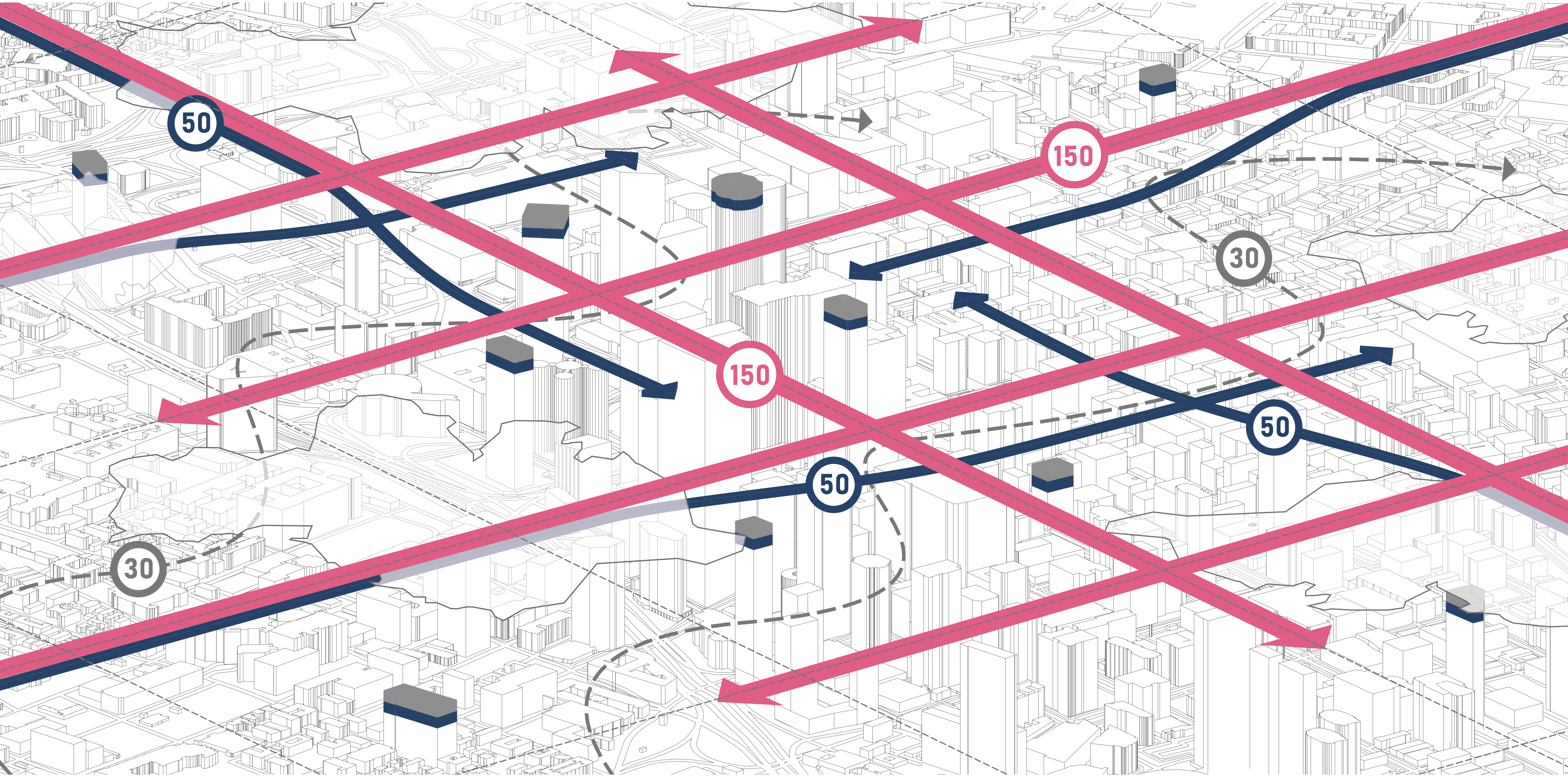
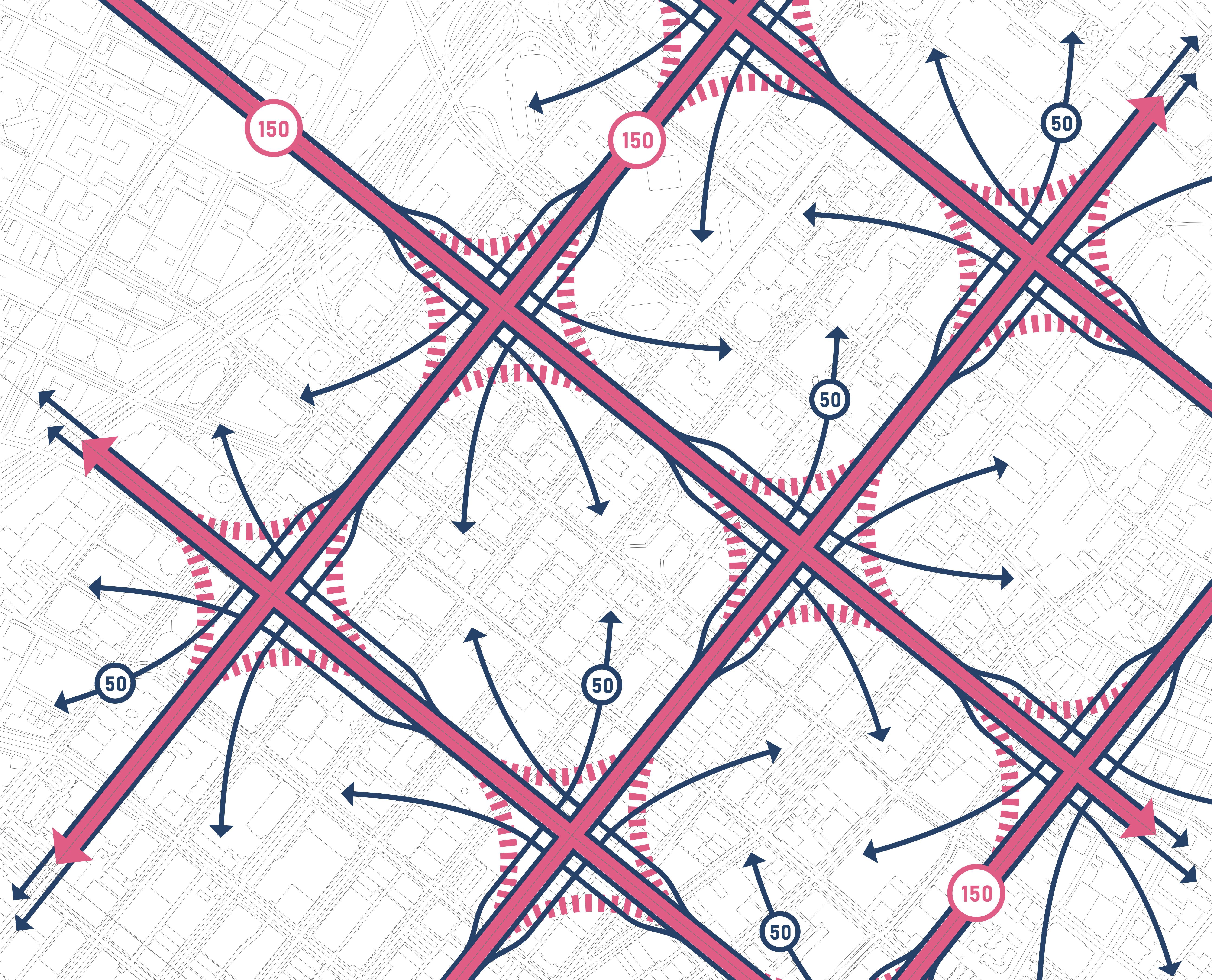


Figure 36. Flight Corridors



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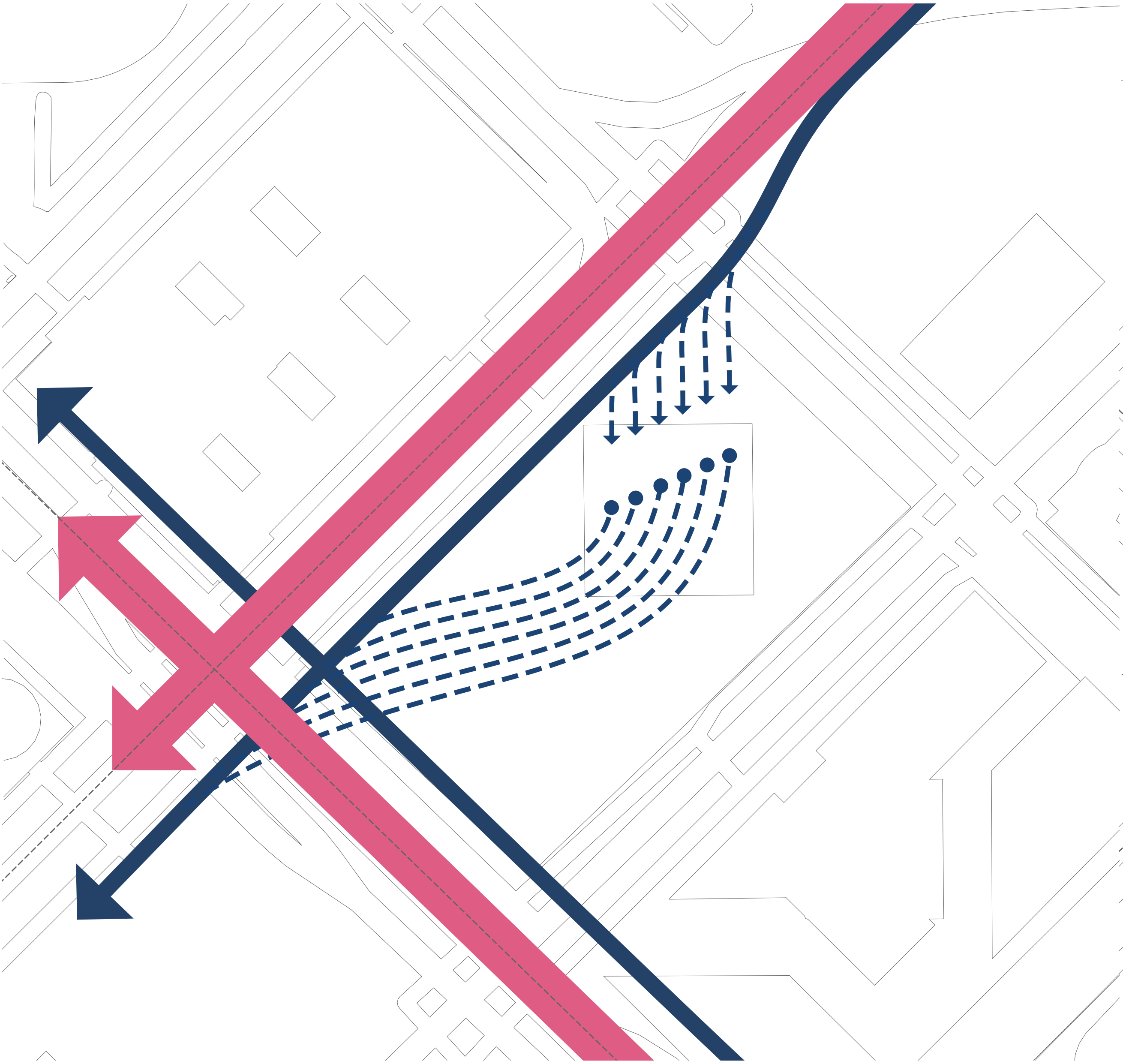


Figure 38. North East Site approach / departure paths

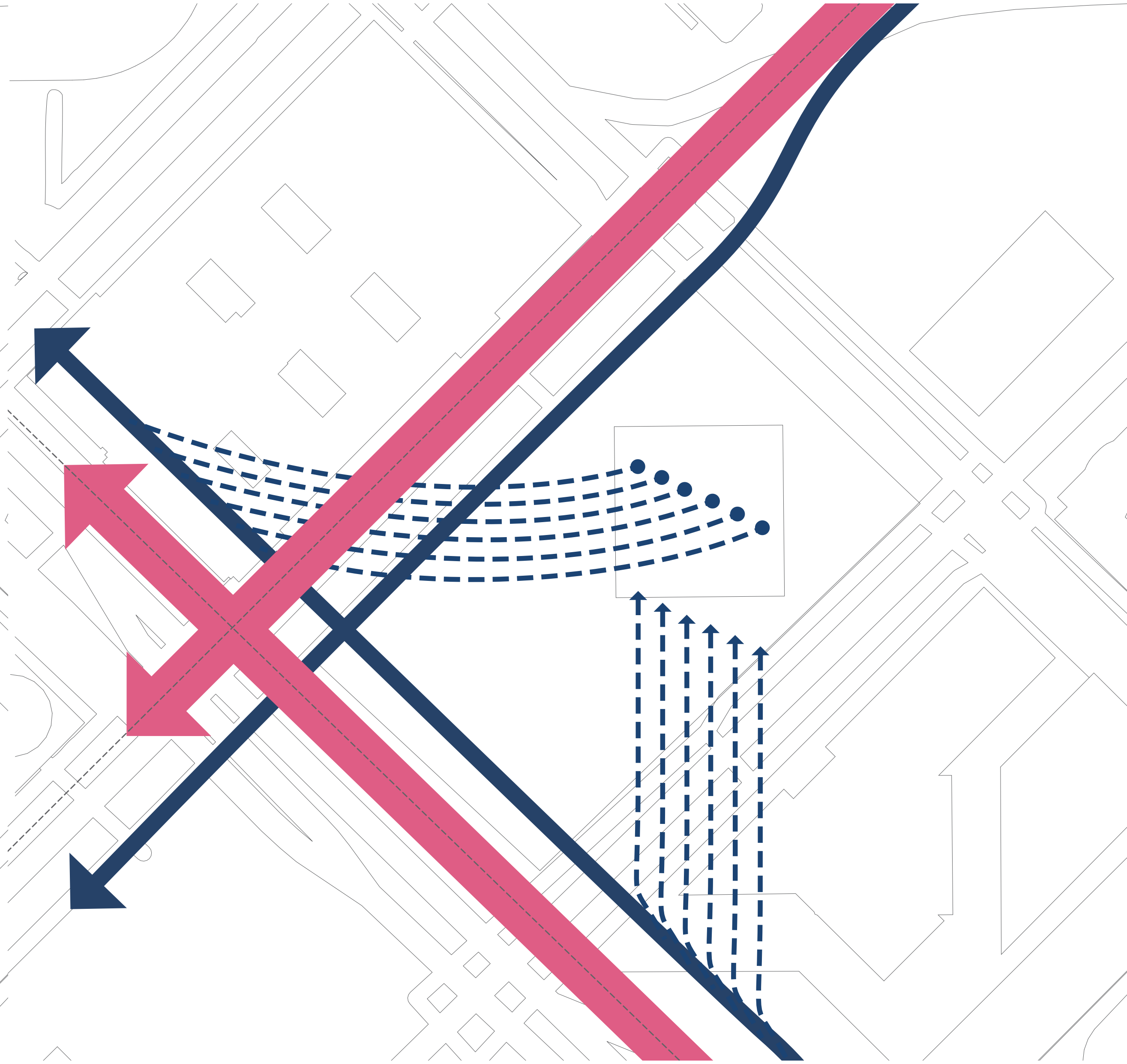


Figure 39. South East Site approach / departure paths

6.2 Drone Station

The project imagines the city and the building in the early days of passenger drone service when the existing buildings need to be reorganized in order to facilitate the technology.

Drone stations would be located on the roof tops to help address noise and privacy issues. The stations do not include any parking spaces as the network is meant to serve as a sharing service. Dedicated facilities for maintenance, battery-recharging and parking would be located outside the downtown core.

The sky station is an orthotic structure in the sense that it enhances the capabilities of the host building and its environs, just as an orthotic device does the function of a limb. It does so by providing greater accessibility and reducing traffic congestion.

Drone stations consist of two levels suspended within a steel exoskeleton. The top level is a **receptacle space** that features a drone-port terminus surrounded by **landing pads**; directly below is a **public space**. Both levels are connected to the host building, to ground level and to underground by four exterior elevators.

As the name suggests, the terminus building accommodates arriving and departing passengers. Landing pads are set within bays whose walls provide shelter from high winds (Fig. 41). Four ports located on each pad vent exhaust air produced by the propellers so as to avoid the risk of a drone stalling as the air that passes through the rotors should not be disrupted or blocked by anything.

After getting off the drone, passengers arrive at the terminus (Fig.43, 44), where they can get a cup of coffee at the coffee shop.

Passengers may then choose to go to the lower level of the station (Fig.45) that features spaces for public events and meeting rooms as well as the work stations with Internet access.

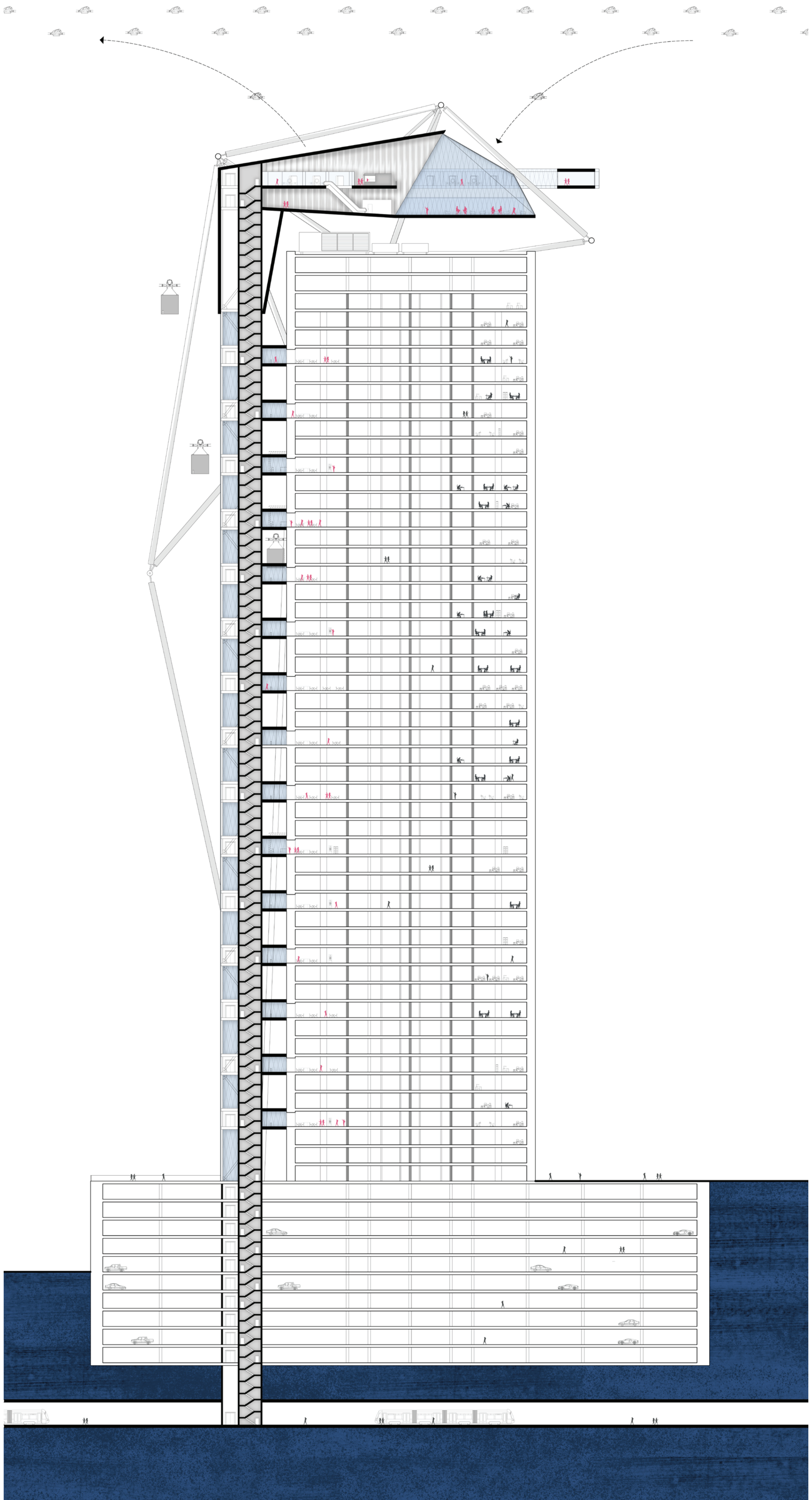
In addition to connecting the host building to the drone station, the elevators would open up new access zones, each a lobby in its own right, thus creating a vertical street. These vertical lobbies might accommodate retail units that would be resupplied by drones (Fig.42).

6.3 Mobile App

To make the drone-sharing system efficient a simple mobile application can be used. All the passenger need do is input his location, destination and the time. The app would then display the nearest station, the flight number of the drone, departure and arrival times, and payment.

6.4 Financing

Traditionally, transportation infrastructure attracts density, which in turn helps finance it. This is usually a lengthy and expensive process, one not always affordable, especially during downturns in the economy. A network of drone stations is, however, relatively inexpensive and can be developed gradually, starting with a small number of stations connecting the downtown core and periphery. Funding would be provided in joint venture by venture capitalists, drone companies, and the owners of the host buildings who would collect a “landing fee” (joint venture).



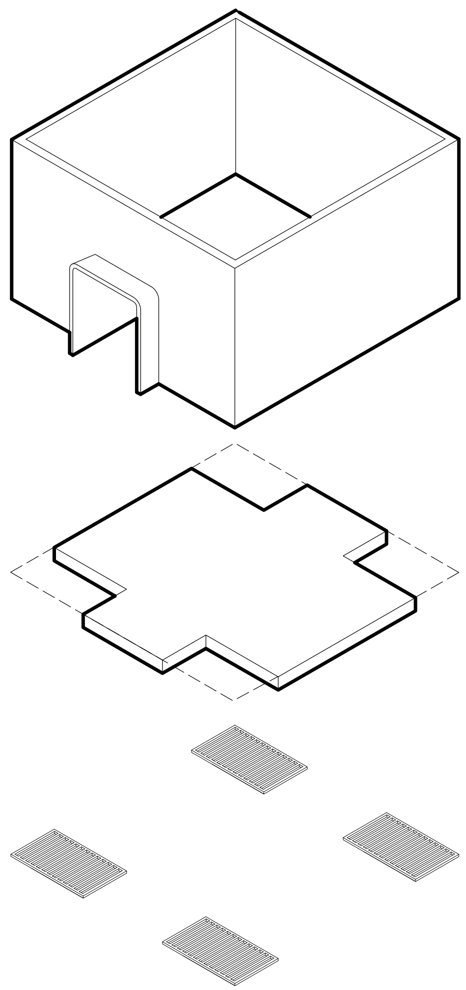


Figure 41. Landing bay

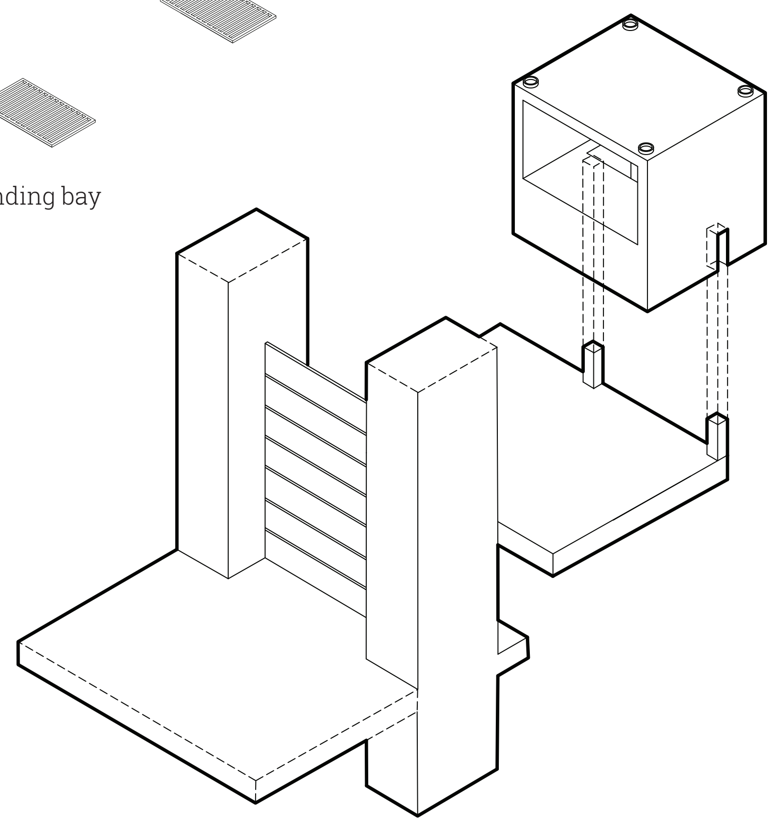


Figure 42. Detachable retail unit

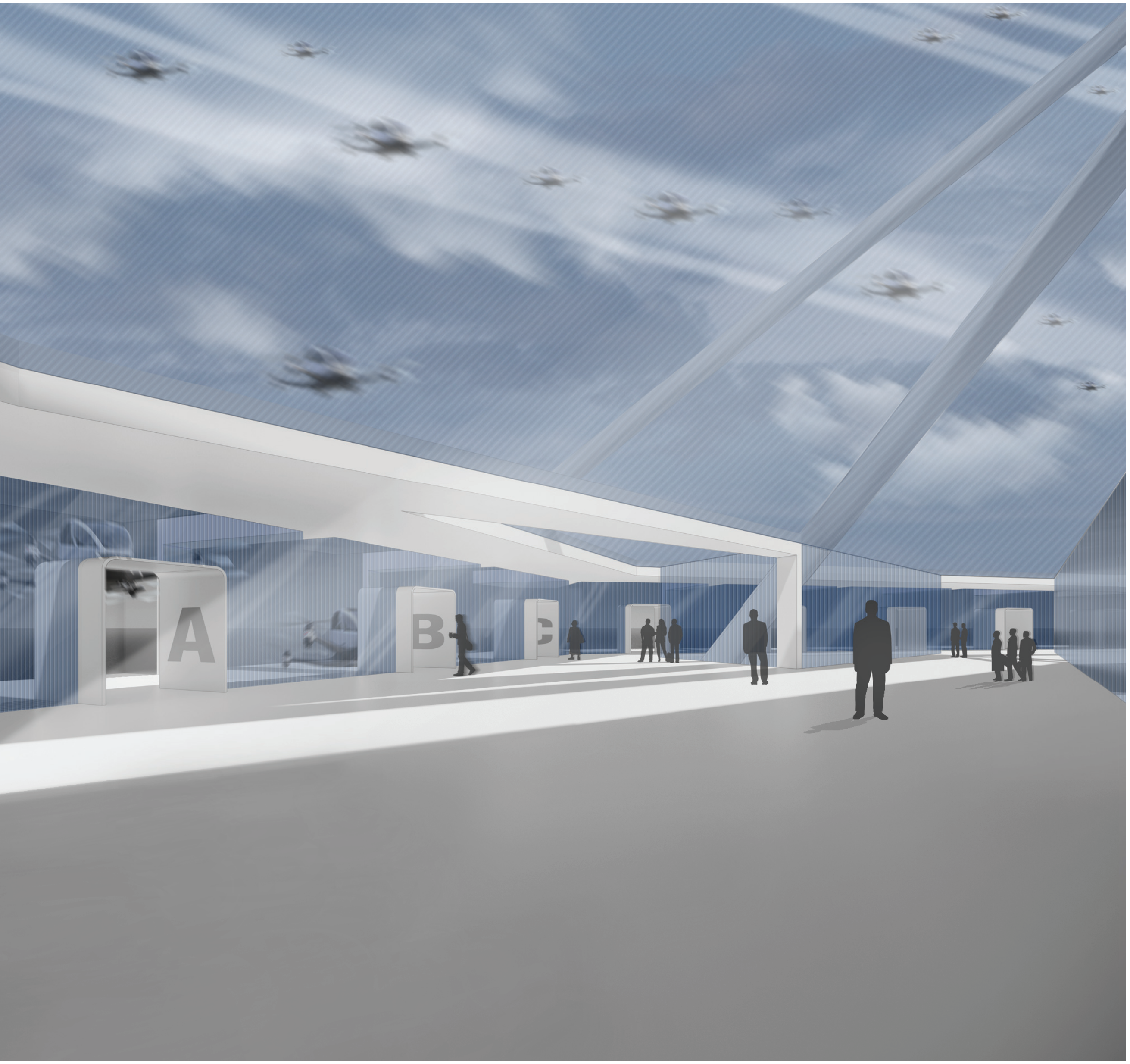


Figure 43. Station interior - upper level

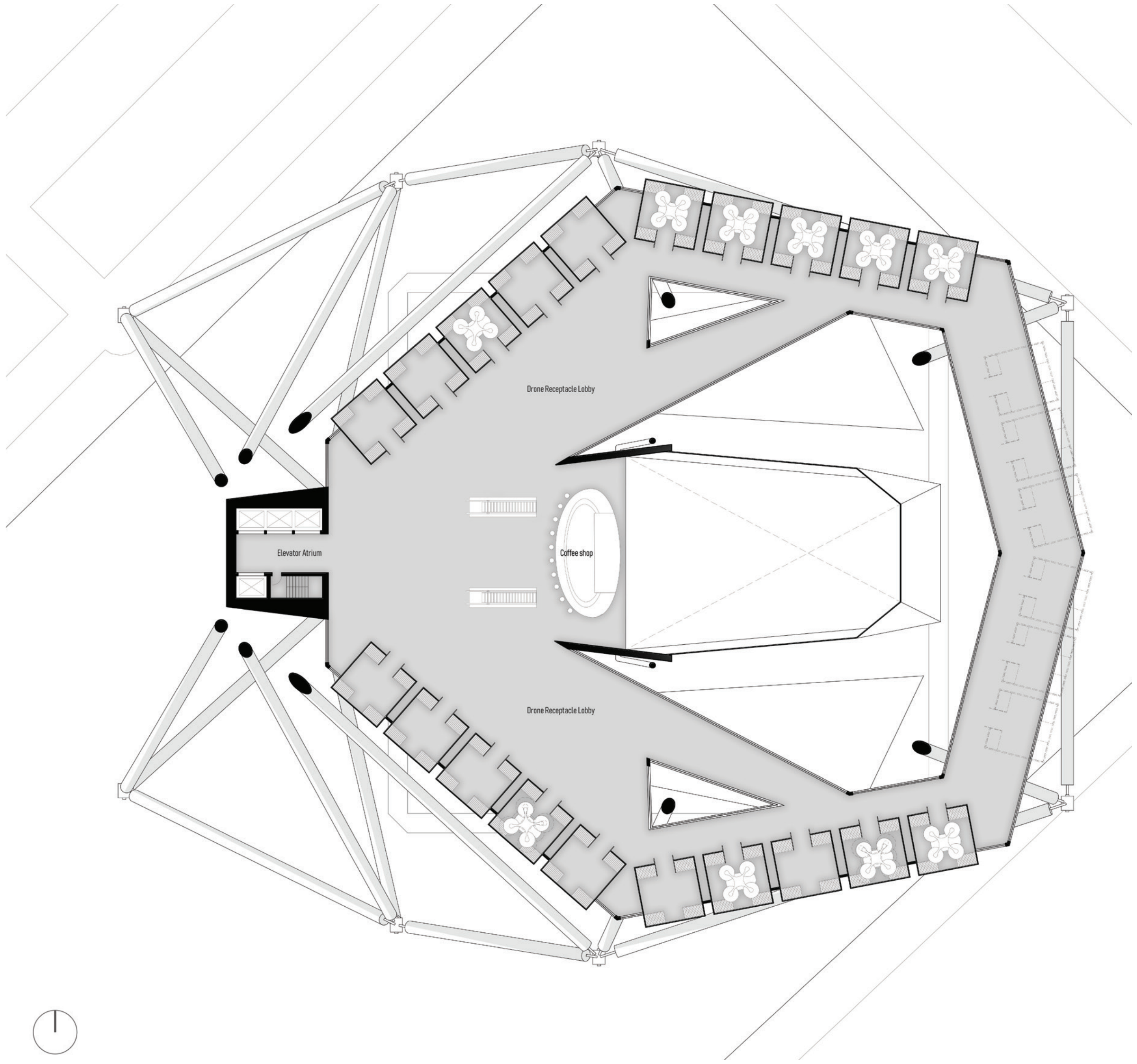


Figure 44. Station - upper level plan

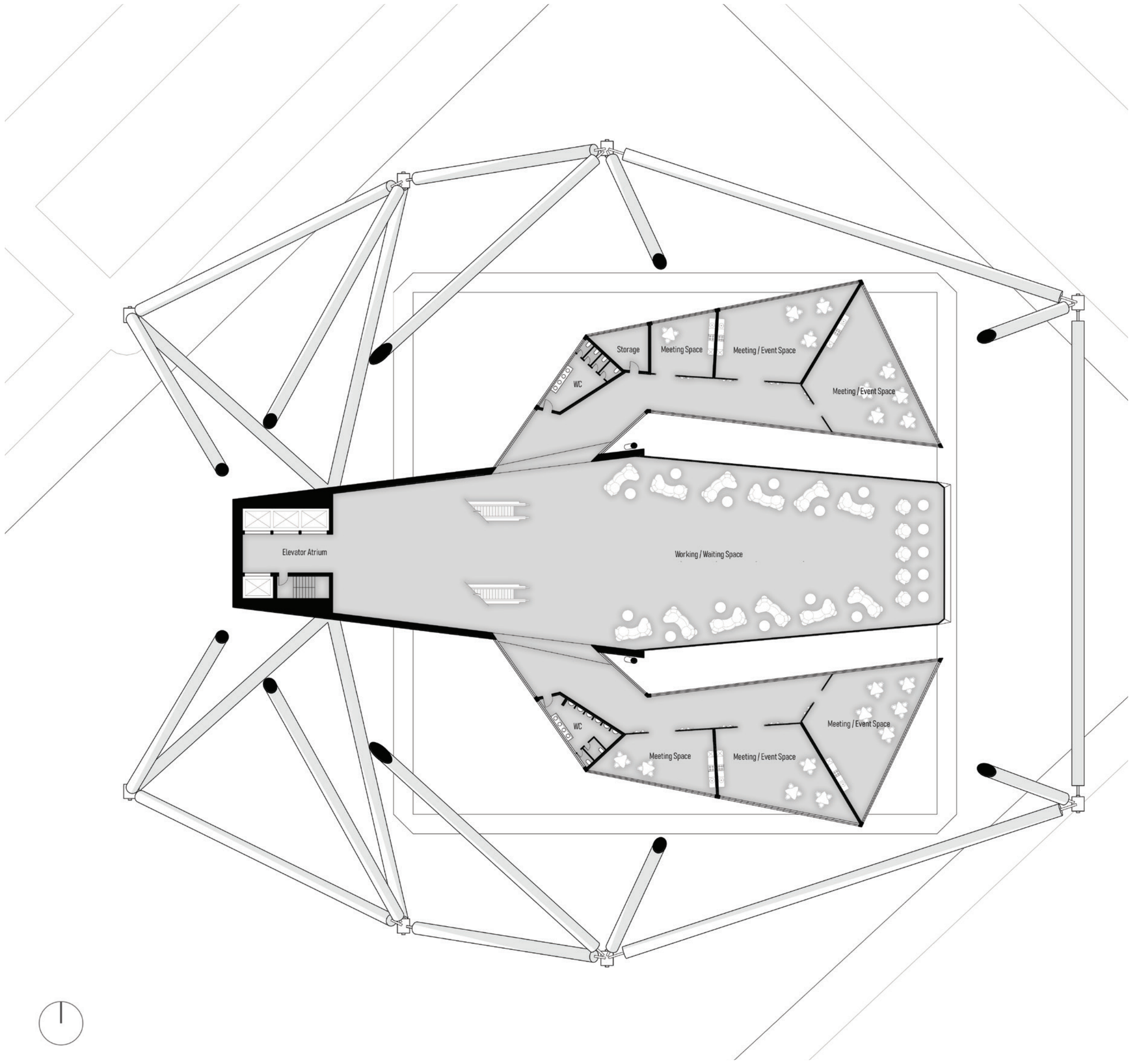


Figure 45. Station - lower level plan

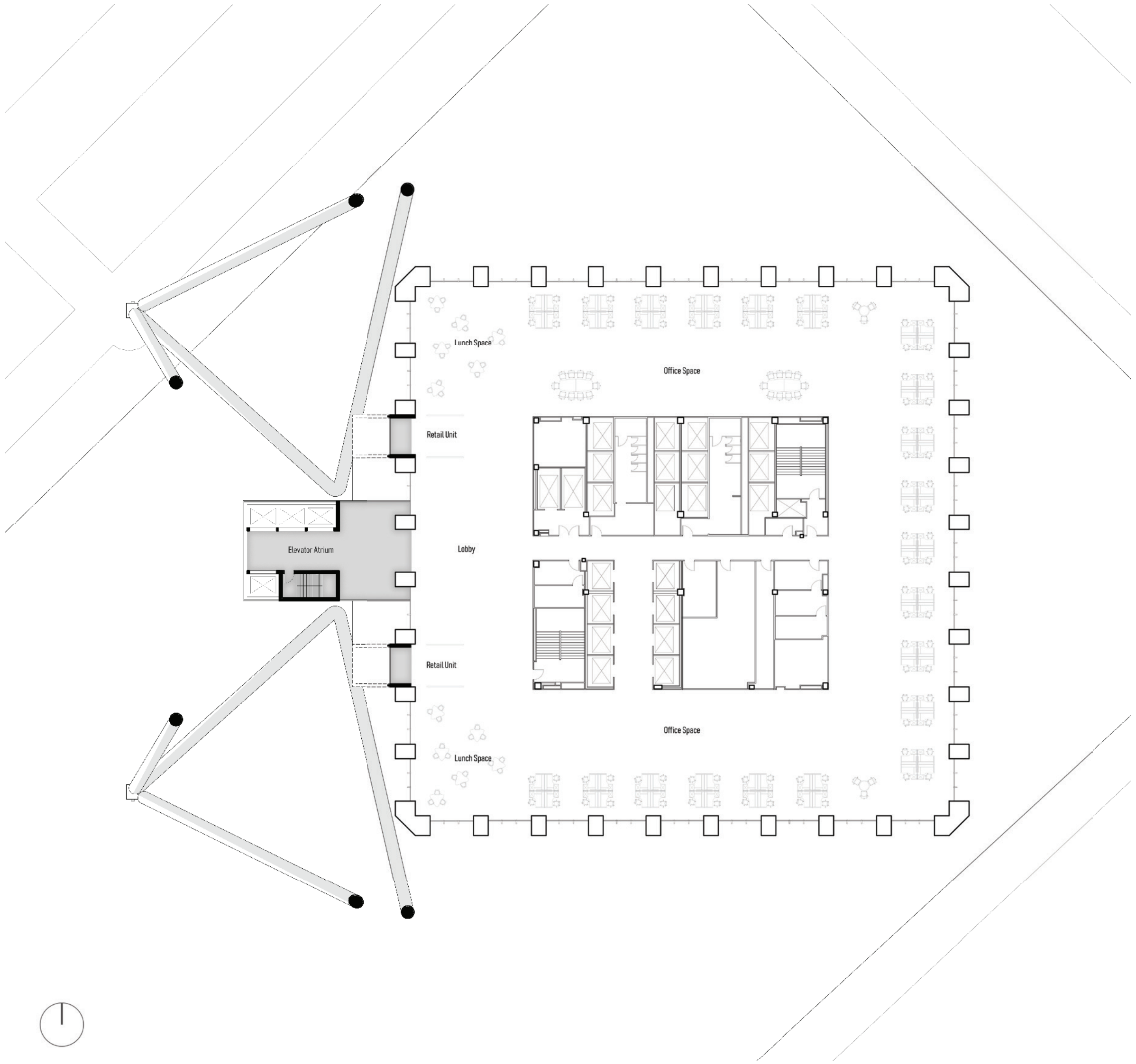


Figure 46. Existing tower - typical floor plan

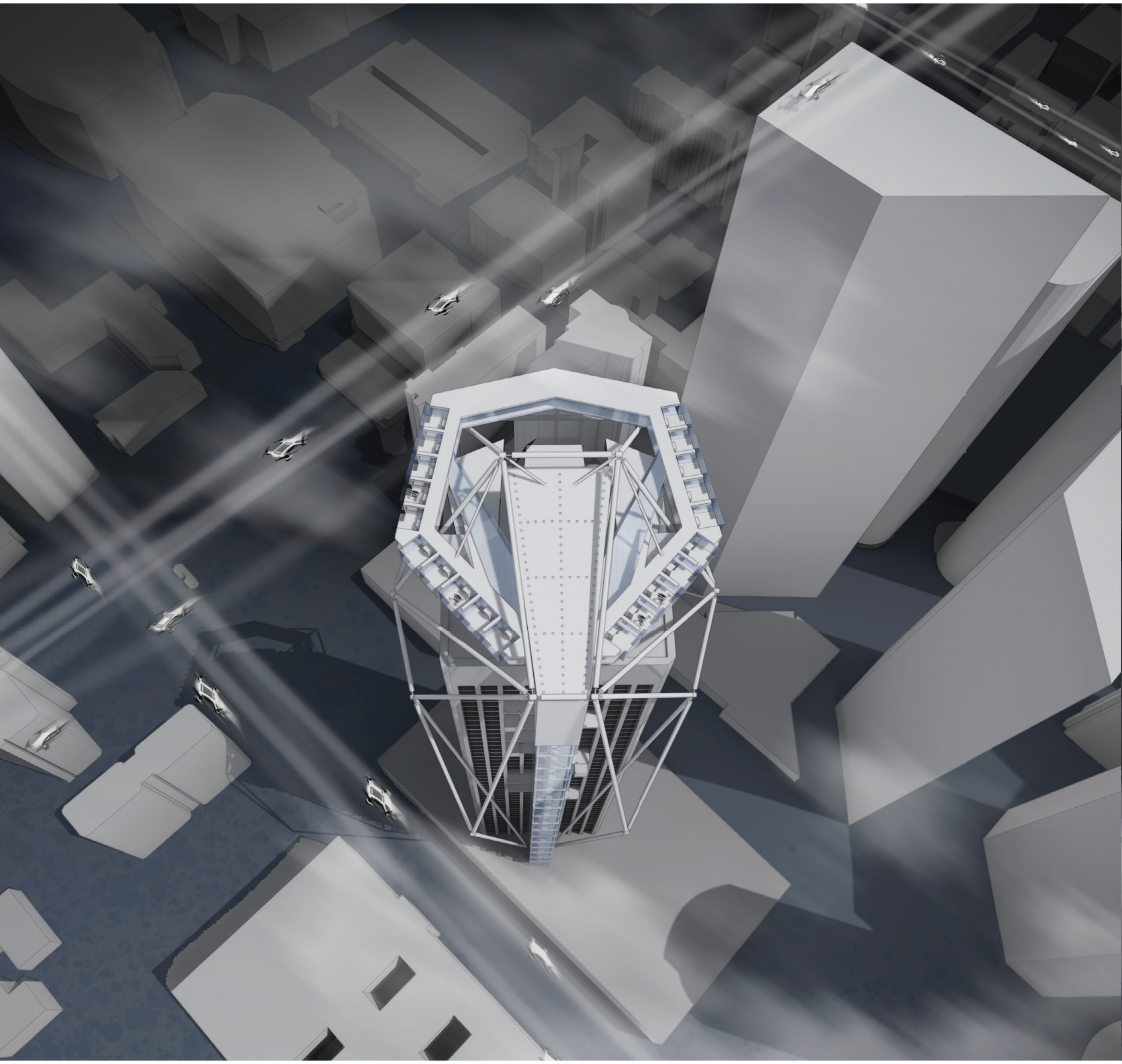


Figure 47. Station - top view

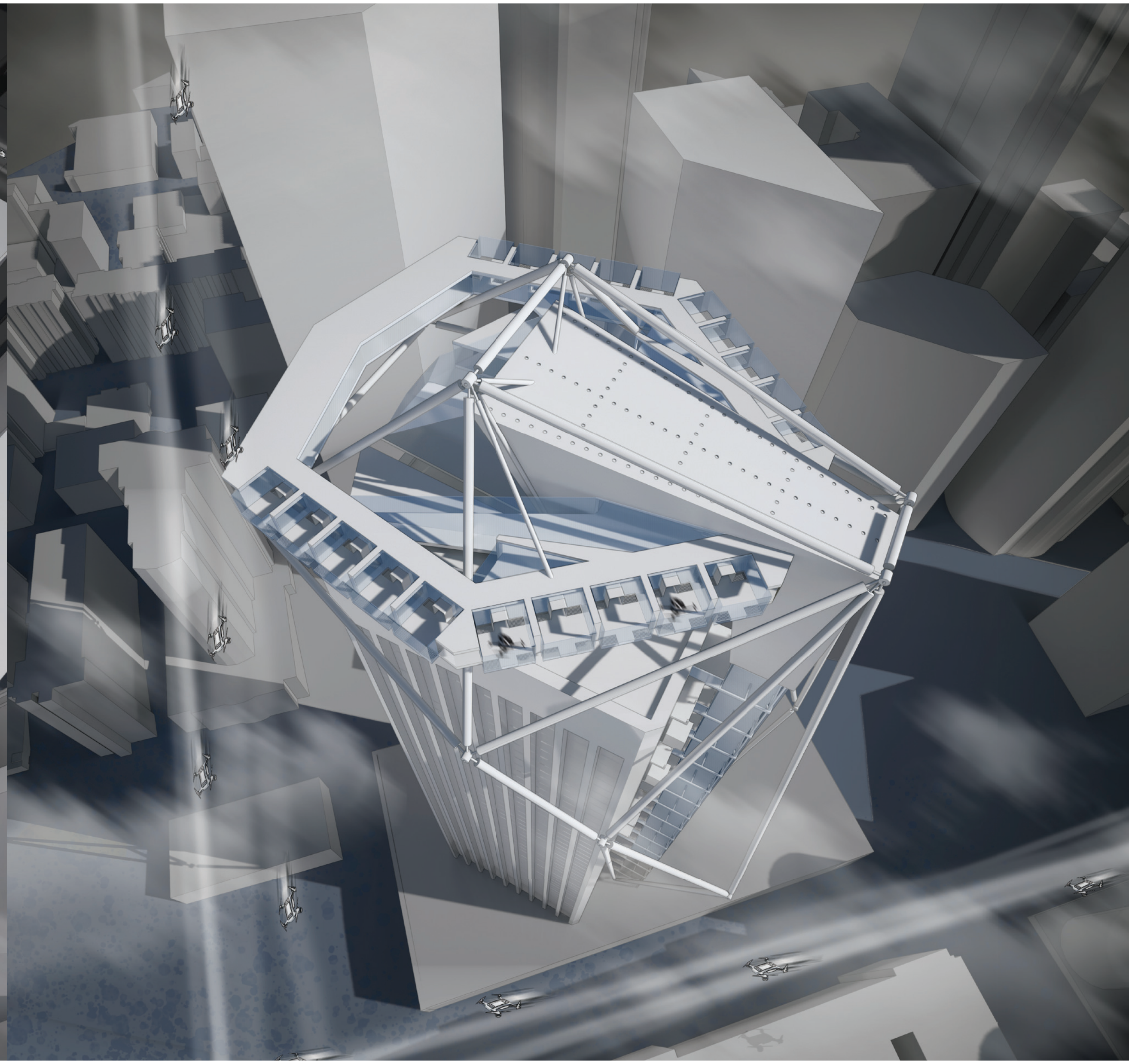


Figure 48. Station - side view

7. CONCLUSION

In conclusion, the project of a drone station is just one piece of the puzzle that would need to be put together in order to enable a true 3D Urbanism that could change the notion of mobility and transportation in cities.

However, the changes introduced by the addition of such a structure—the form, size, and program of which would mostly depend on the needs of each individual city and building—will partially break the conventional image of many buildings and their features, such as form, circulation, ways of access, and accessibility as well as the way we perceive and interact with them. This is the point where the fight for 3D Urbanism starts.

8. PRECEDENT STUDIES

8.1 The Aviary

The Drone Aviary is a Presidential Library project conceptualized and developed by Future Firm, an architecture and research practice, dedicated to the presidency of Barack Obama. It is an artifact library that uses drones to connect people with library resources (Fig. 49). The creators of the concept assert that the library no longer relies on books; rather, it is a repository of digital data ("Obama Drone Aviary"). The building has few staff members, as drones do most of the work.

The structure of the building is simple. It has the shape of a hollow cylinder (Fig. 50) with hexagonal niches ensconced within the walls (Fig. 51) that serve as nests for drones. It has no floors or levels; and the structure sits directly on the ground, so upon entering one is confronted with a grass field. The library is intended to serve as a bridge connecting people and history.

Figure 49. The Drone Aviary atrium

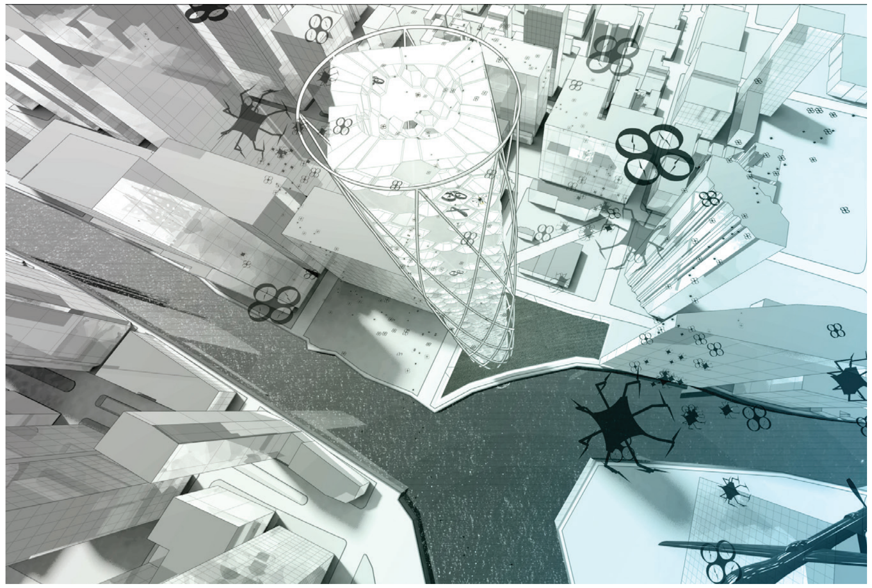


Figure 50. The Drone Aviary exterior

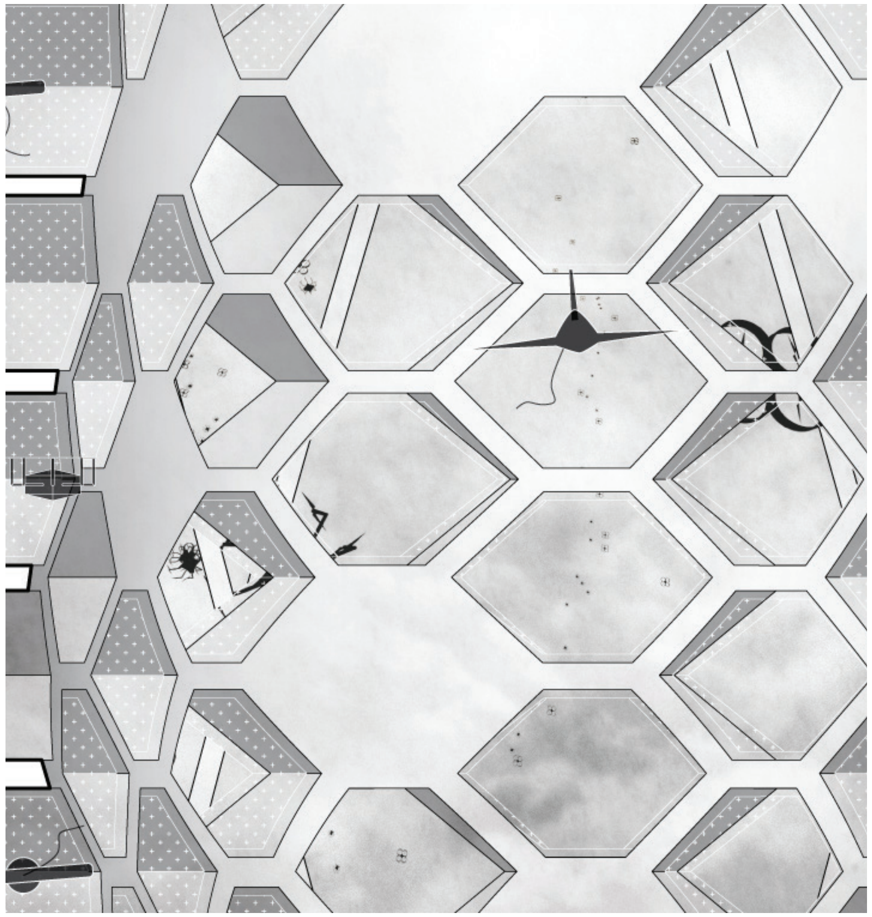


Figure 51. The Drone Aviary hexagonal niches

8.2 The Hive

Located in New York, the Hive is a prototype drone terminal, replete with docking stations for delivery drones (Fig. 52). The entire façade of the tower features thousands of niches capable of accommodating different types of drones.

Lower Manhattan where the tower is located consists primarily of skyscrapers, which poses a problem as it is not clear how delivery drones will interact with this kind of urban environment. In particular, the question of where drones are to land while delivering packages remains to be addressed. The façade of the proposed tower is designed to serve as a landing pad for flying robots, but the surrounding buildings have a limited capacity to accommodate drones. Nor has the noise level issue been examined let alone addressed.

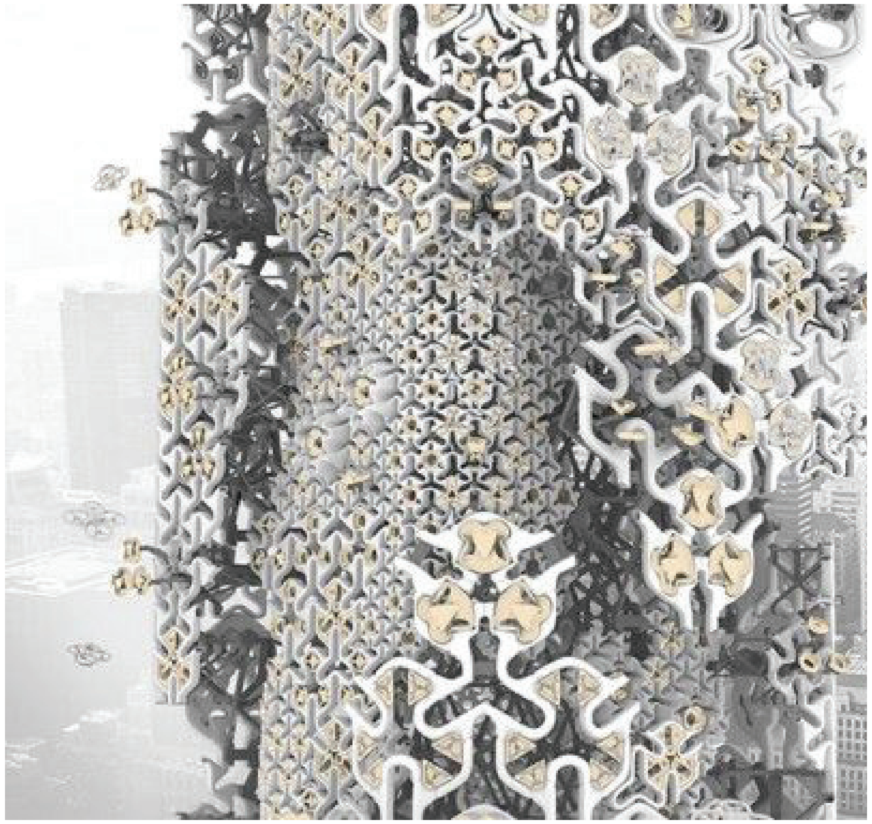


Figure 52. The Hive

8.3 The Droneport

The Droneport was designed by Foster + Partners as a humanitarian project for Africa (Fig.53,55). Its primary purpose is to accommodate long-distance drone deliveries of medicine. The idea is to create a network of droneports across Africa to serve as transit stations.

The Droneport consists of repetitive structural elements that offer "a taste of a low-tech architecture designed for a high-tech revolution (Heathcote)." The vault is designed to be easy to assemble, using standard brick construction (Fig.54). The structure is shaped like a canopy beneath which are located the distribution center and some public spaces (Heathcote).

At first glance the form of the Droneport appears to have nothing to do with drones—a not inaccurate assessment. Nowhere are docking stations to be seen or any other elements that might suggest that this structure is intended to serve drones. Instead, it is a piece of vernacular architecture. It is, in fact, designed to shelter people and drones from the sun, an oasis where cargos drones can be unloaded.

While this project is not intended to study urban applications for drones, it does highlight an important application for UAVs, namely saving lives.

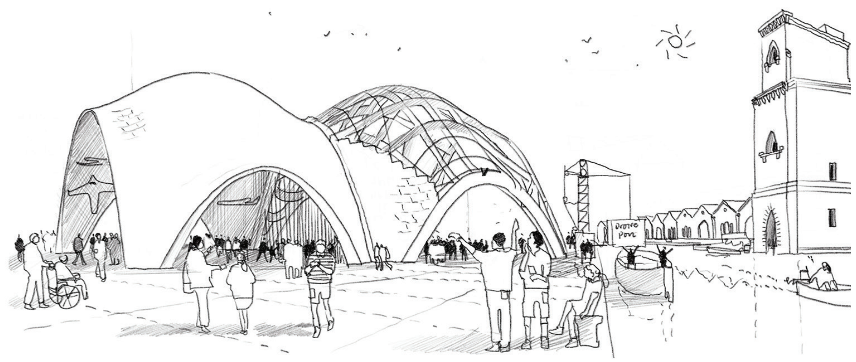


Figure 53. The Droneport sketch

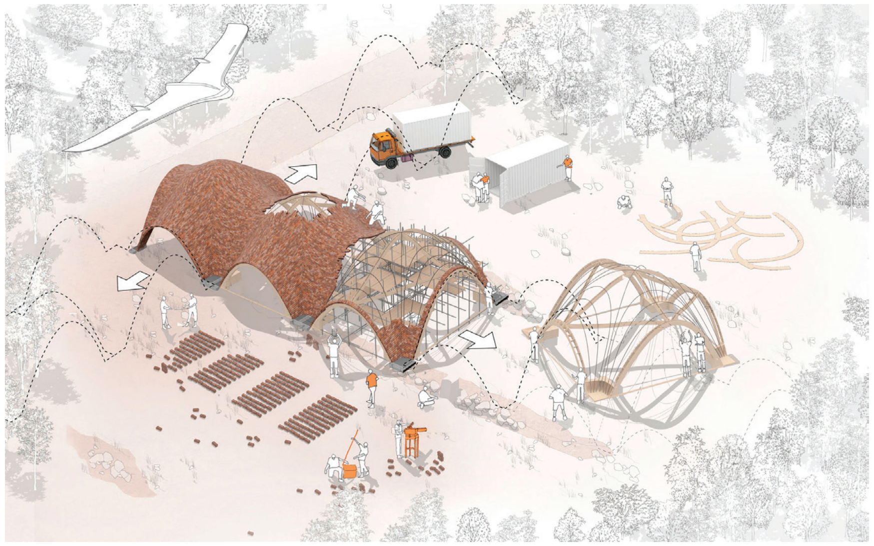


Figure 54. The Droneport structure

Figure 55. The Droneport concept render

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