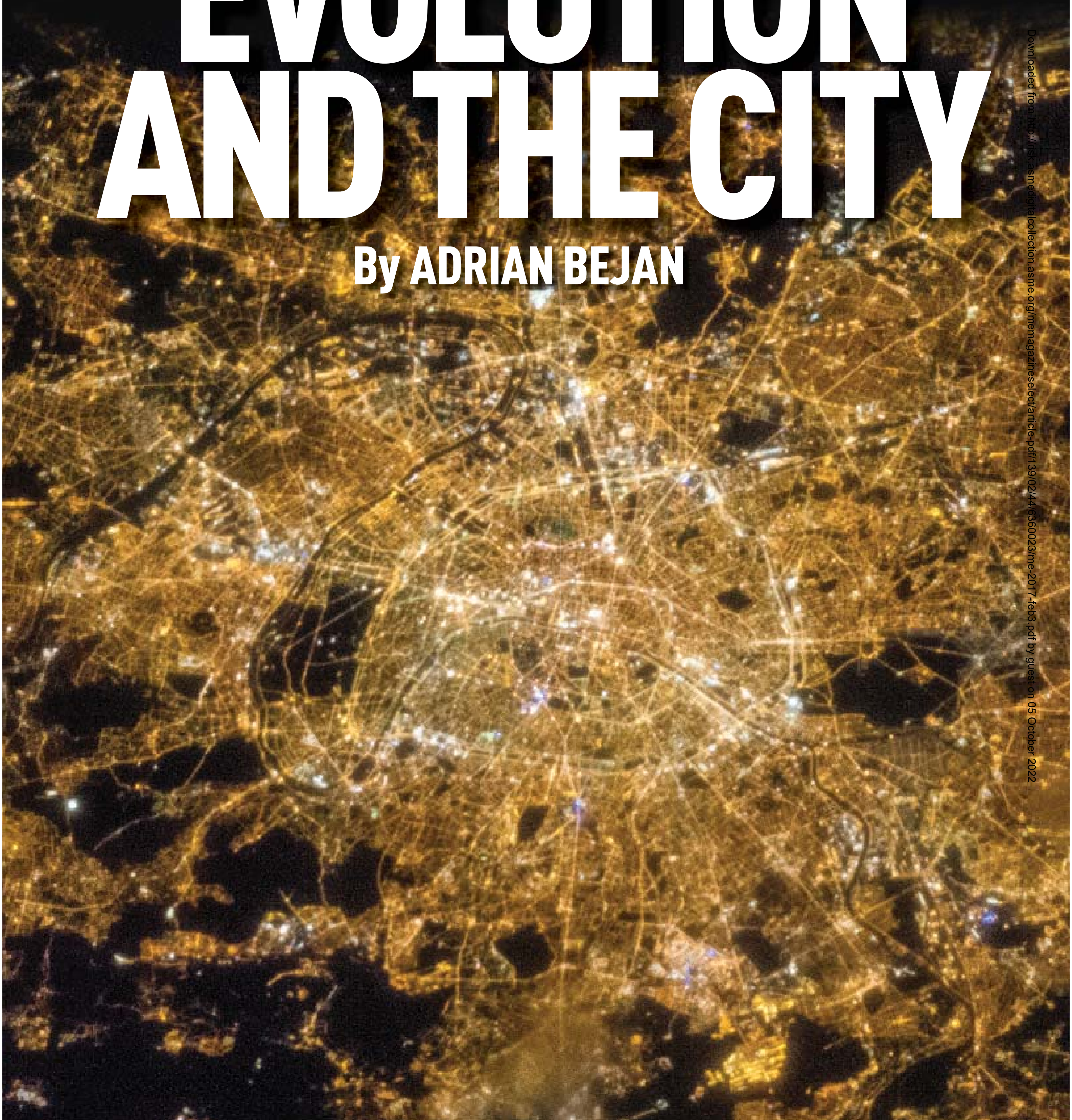
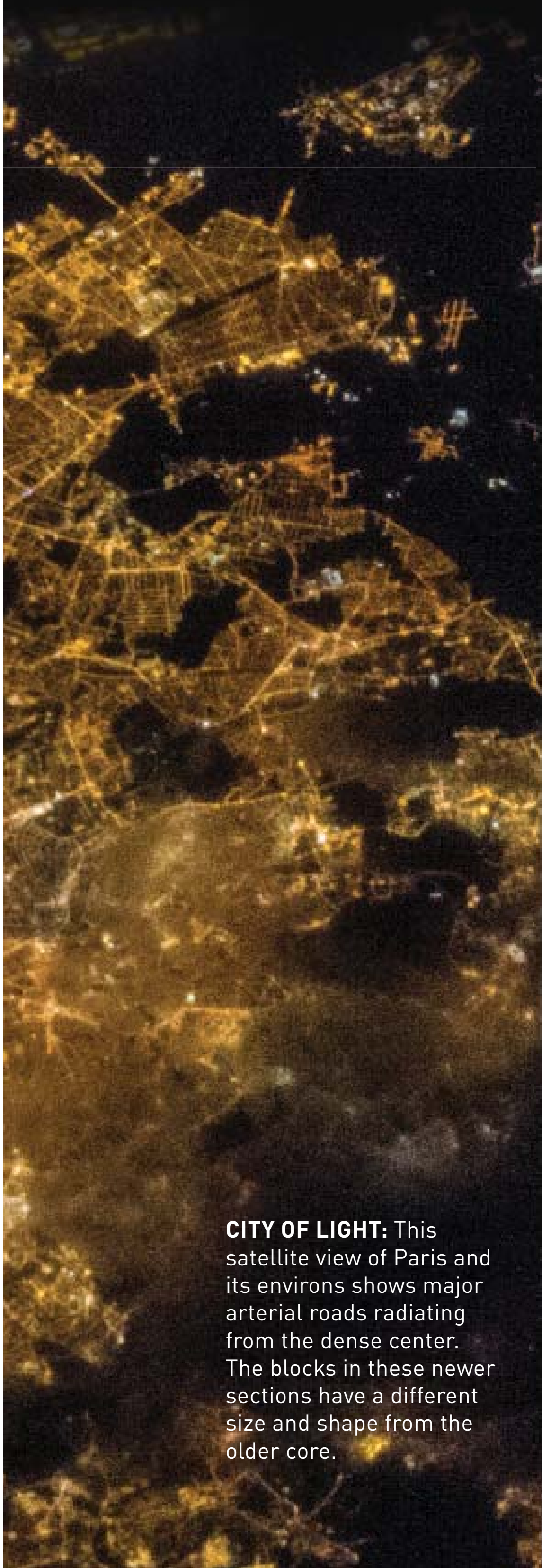
EVOLUTION AND THE CITY

By ADRIAN BEJAN





CITY OF LIGHT: This satellite view of Paris and its environs shows major arterial roads radiating from the dense center. The blocks in these newer sections have a different size and shape from the older core.

A lot of care and attention is paid to urban planning, but the evolution of human settlements happens naturally because it is governed by a law of physics.

The Occupy Movement, which saw protesters seize public squares all over the world, was intended to highlight wealth inequality and lack of freedom. But it provided an unintended lesson on the design of cities: Access is the future of urban design.

That was evident to observers who compared Occupy Wall Street in New York and Occupy Central in Hong Kong. The squatters in New York brought a wide section of the city around its Financial District to a standstill in 2011, and that gridlock produced strong resentment from residents and businesses. The reason for the standstill was the interrupted flow of pedestrian and auto traffic in downtown New York, which is mainly on a horizontal plane at street level. For all its skyscrapers and subways, much of New York is two-dimensional.

OCCUPY CENTRAL: Pedestrian bridges and underpasses in the business district of Hong Kong enable workers to bypass even large protests.

When I visited Hong Kong during the height of the Occupy Central movement, I saw that the protesters squatting there did not stop the pedestrian and auto traffic because that city's central business district is "vascularized" in three dimensions, with overpasses, underpasses, and loops everywhere for pedestrians and vehicles. Compared to New York, access for inhabitants and businesses in Hong Kong was not impaired. While the protesters were forced out of Zuccotti Park in New York after eight weeks, Occupy Central was tolerated for ten months.

It makes sense that the next step in urban design should be to add dimensions. Cities metamorphose as they grow. They exhibit the phenomenon of vascularization on a grand scale. Avenues, one-way loops, overpasses, underpasses, beltways, and subways are new channels that join the old channels to ease the movement of the growing urban population. Paths occur where people walk freely, not the other way around. People disobey when forced to follow a rigid path that is not of their own choosing.

The occurrence of channels and vasculatures is not a new phenomenon. Its first manifestation was the dirt path between a few homes in a village, with peasants and oxen walking on it. Paths were joined by alleys, streets, and avenues. Crooked streets once traced by farm laborers and animals became straighter and wider.

This evolution is as old as civilization. Even the city grid that many associate with Manhattan dates back to the cities designed by Hippodamus of Miletus in the 5th Century BCE. In evolution, what works is kept.

This raises many questions about the arrangement of streets in the city. Why are the large few and the small many? Why does hierarchy happen? Why is a large street connected to only a handful of smaller streets that are oriented sideways? Why does the city traffic design change discretely, in stepwise fashion, and not continuously? Why is the city block shaped like a block? You can find the answers in physics.

Man, ox, carriage, and car

The city is a living, flowing system. It morphs freely as it flows, which is how it derives its lasting power, its life. And we can analyze the organization of a city in terms of how well it enables humans to move from any point to the whole area.

Consider the simplest type of human settlement, one with a single point of prominence such as a central market or harbor surrounded by houses scattered across the landscape. The quickest route to each house from that central point is a straight line. In the most primitive settlement, footpaths radiated outward from the center of the hamlet. This radial pattern of access paths survives today, especially in perfectly flat or sparsely populated rural areas.

In time, the design of movement changed. The ancient market became a larger village with a constellation of almost equidistant tiny villages and farms. The radial length in any such "wheel" was set in antiquity by the distance that the pedestrian and the ox could cover in a few hours, so that the round-trip to the mill or the marketplace could be made during daylight. The order of magnitude of that distance was 10 km, and that's what we see on today's maps.

Horse-drawn carriages eventually disrupted that radial pattern. Humans then had two modes of travel—walking and riding in a carriage—each with a characteristic speed. Because it was impossible for every person to drive a carriage in a straight line to every possible point on the area, trips were divided between the two modes. There was a walking leg, a riding leg, and another walking leg.

In accordance with Constructal Law, the natural way to assemble and connect a road and street network is to ensure that travel time is reduced at every turn and with every change in the flow design. As a result, for a typical trip the time spent traveling slowly is roughly equal to the time spent travelling fast. Of course, that means that the distance covered by fast travel is much greater than the ground covered at slow speed. Imagine a typical commute by automobile: It begins with a slow drive over surface streets, then high-speed travel on long-distance freeways, and then slower speeds as the car exits the highway and moves across surface streets to the final destination.

This principle—slow travel over a shorter distance, fast travel over a greater distance—applies to all travel time, whether it's in the city, on

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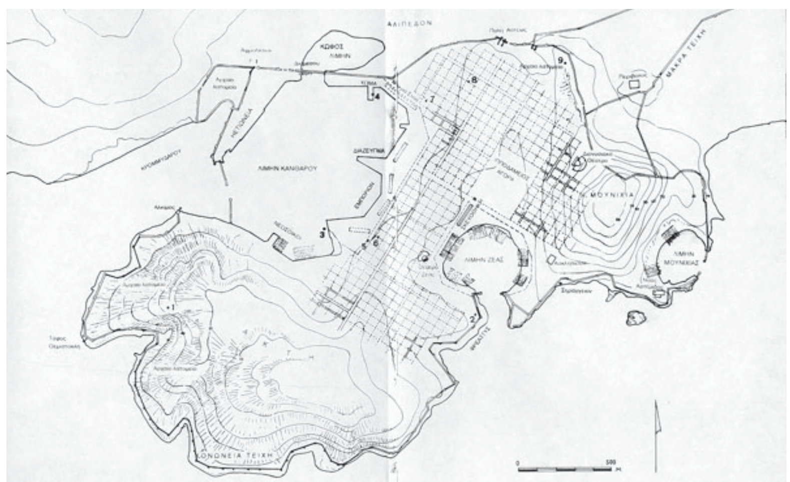
a highway , or through the air. It's a basic law of physics, and is used to describe how light refracts as it enters and exits glass. Light travels the fastest and most efficient path, not simply the shortest.

The ancient center of an old city such as Rome has small, square blocks with short streets, which serve as a reminder of the vehicles of antiquity, the ox pulling the cart and the horse pulling the carriage. There is a sharp contrast between the ancient center and the newer neighborhoods that emerged during the automobile era. The latter have longer streets, slender city blocks, and more homes per street.

In a city, the smallest scale time balance is between walking from the house to the car and then driving on the small (short, slow) street. At the next length scale, the balance is between riding on small streets and riding on avenues (long, fast), then on to even larger scales: larger avenues and highways. From the highways, the flow design of the city links to intercity train and air travel that includes short and long flights.

Physics applies to human life as well as inanimate movement and flow. We seek the fastest and most efficient path, not simply the shortest. That aspect determines the movement of every individual as he



PIRAEUS: The original plan for Piraeus, the seaport of Athens, was drawn up by Hippodamus of Miletus in the 5th Century BCE. That plan (above) featured a street grid made up of largely identical square blocks. After the city's destruction, Piraeus was rebuilt in the 19th Century following a grid (left) of longer rectangles suitable for faster travel by carriage and tram as well as by foot.

moves through the three-dimensional space of the city, and explains the often baroque shapes the cityscape takes on.

Predicting the suburb

Not all of the vascular features in the city are shaped like blocks. Some are shaped like veins, like the tunnels under a city center or beneath the harbor between Kowloon and Hong Kong Island. Even more stunning are the circular highways around a city, for example, Le Périphérique in Paris and the Beltway in Washington, D.C. All of these features of city evolution owe their existence to the need for easy access of movement.

The construction of a beltway becomes attractive when it is quicker to skirt the margin of the city at highway speed than it is to drive a straight line through it.

Travel time depends on the factors of urban design—one-way streets, stop lights, safety-minded speed limits, and the inevitable congestion—as well as the ability of highway engineering to accommodate higher speeds and greater vehicle capacity. As technology improves to allow faster highway speeds (or congestion on existing roads degrades those speeds), a new and larger beltway farther from the city center may be even more attractive than the first, inner beltway. If we knew the effect on travel times of beltway routes of differing distances from the city center, we could use this evolutionary principle to determine not only the size and location of the new beltway, but also when it should be built.

What's more, across the new neighborhoods sandwiched between the inner and outer beltways, the speed will be greater than in the city center, because new neighborhoods have longer blocks and wider streets. This evolutionary aspect is due to the change in vehicle technology, which means a change in speed.

Constructal Law, then, not only describes the natural tendency that

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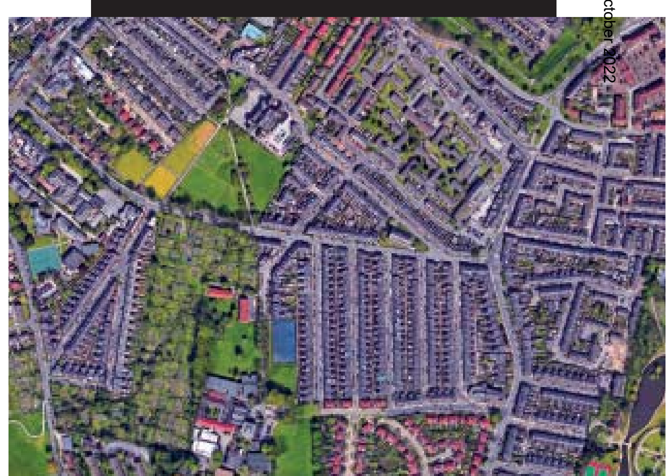

RING ROADS: When travel directly through the center of a city becomes slow due to congestion, engineers devise ring roads such as the one in Shanghai (right). The optimal location for a ring road is based on travel time through the congested center as well as the anticipated speed along the beltway. As those ring roads fill up, new beltways are needed. Houston, Texas, is now in the process of designing and building its fourth ring road (above).

MEDIEVAL TO MODERN: The old center of York, England, (far left) is comprised of small, irregular blocks bisected by alleys, or "snickelways," surrounding the ancient cathedral. Districts built in the 19th century (middle) feature longer blocks with more row houses facing each block. York's modern suburbs (right) have even larger blocks and are designed for access by automobile. (All photos are on the same scale.)

shapes the city grid, it also predicts the emergence and the form of the suburb.

Why is this important to know? If we can anticipate the urban features that emerge naturally from the need for greater access, we can plan ahead and design with confidence the features that not only serve the population, but do so with staying power. It is much more economical to build a new road in the right place and at the right time than to build several roads that are only partway successful. Predicting the future and constructing changes based on a proven scientific principle is much faster and more economical than trial and error.

Here, in the evolution of the city, we see how useful the science—and the physics—of evolution is. With the physics of evolution we predict the future.

Thanks to modern technology, urban design expands not only outward, into suburbs, and inward, toward dense city centers, but also vertically. A building or a subway station is a three-dimensional living space with two aspect ratios, the floor shape and the profile shape—that is, the number of floors. In the best-designed modern urban settings, this three-dimensional thinking about the flow of people extends to complex public spaces, which is why Hong Kong could function during Occupy Central while Occupy Wall Street strangled New York's Financial District.

The city is a live flow system with freely changing architecture, many small streets, few large streets, and beltways. We, the people, are what flows. The morphing design strikes us with natural hierarchy, at every level and in every flow: pedestrian movement, traffic, freight, and emergency evacuation.

The changing city opens our eyes to the physics of evolution—and the physics of life. **ME**

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