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Underground City-Planning
A French born Concept for Sustainable Cities of Tomorrow

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ABSTRACT

The concept of Underground City-planning may be traced back to year 1855, when Paris sewers were designed big enough to accommodate many utilities inside; at the turn of the century, architect Hénart proposed to place under the street a "technical storey"; instead the Paris metro began, taking the best from previous networks. It is world first by the ratio of underground sections. As soon as the twenties, a first draft of underground roads has been sketched to help solve traffic jams and from 1932, architect Utudjian introduced the concept of Underground City-planning, followed around the 60s by dozens of underground car parks and underpasses, then by two big underground developments Les Halles and La Défense. After novel uses coming from the US, Scandinavia, and Japan, the 80s were marked by the doctorate thesis of Jacques Brégeon and the "LASER" project of underground motorways. They gave birth to an association under chairmanship of Prefect Doublet, to promote a better use of subsurface space. Studying constraints from both geology and law, it designed various projects and took part in a national research team on technical galleries for utility networks. The aim of the paper is to emphasize the benefits of underground space for giving cities sustainability.

Keywords: Underground; Geology; Law; City-planning; Mass transit; Utilities

1. INTRODUCTION

In 1932, architect Edouard Utudjian defined the concept of underground city-planning, under the French name "*Urbanisme souterrain"* and he drew the lines for its developments; he created a national association, GECUS (Study and coordination group for underground city-planning) and later an international one (CPITUS Permanent international committee on underground city-planning techniques) ; he launched a journal, *"Le Monde souterrain"*. Though it proved to be too early for putting so novel ideas in full practice, many among the projects of his team, were to be built along the decades to come, two regional express metro lines, crossing in the very heart of Paris, many underpasses and more than fifty underground car parks (more and more have been built since).

The birth of Underground City-planning could be traced back about 1855: under prefect Haussmann, civil engineer Belgrand designed Paris sewers big enough to accommodate many utilities inside; half a century later, architect Hénart first proposed to design two-storey streets, with narrow gauge tracks for freight transport. About the same time, civil engineer Bienvenüe was in charge of building the Paris metro (from 1898 to his death). He took the best from previous metro networks. The "metro era" solved the mass transit problem of big cities for decades, up to the explosion of car traffic. The Paris metro is world first by the ratio of underground sections. Then, as soon as the twenties, Paris began experiencing the traffic jams and a first draft of underground roads has been sketched by GECUS.

In France a new impulse originated from the doctorate thesis of Jacques Brégeon (1983), the "LASER" project of underground motorways under Paris in 1987 and the birth of association "*Espace souterrain*" in 1988, under chairmanship of Prefect Maurice Doublet (a man of many achievements in underground projects in Paris, and under the Channel). Recently introduced as a specific committee into the French Tunnelling Association this party is very active today, drawing many proposals, studying constraints from both geology and law and taking part in conferences worldwide. It took part in a national research project team on technical galleries for urban utility networks, under code name "Clé de Sol" (musical G-key, or a key to open the ground). Since a few years, "Urban problems, underground solutions" is the theme of an ITA working group. The French WG is chaired by professor Sabine Barles. Both are prepared to discuss how going underground will make cities more sustainable.

2. BIRTH AND BEGINNINGS OF *URBANISME SOUTERRAIN* IN PARIS

2.1. Paris underground quarries

Paris is built on both banks of the Seine, flowing between low plateaus on either side, Montmartre and Montparnasse. For centuries those rather flat hills provided building stone for walls and monuments, and gypsum for plastering wooden houses, a defence in case of fire: contrary to London, no Great fire happened in Paris. Gypsum has been extensively shipped abroad, even to America. The early quarries were opened along hillsides, then extended under the plateaus, before the city covered them: about one tenth of the surface has been undermined (the same was to occur later with many suburbs). After deadly accidents occurred, through caving under streets or buildings, King Louis XVI ordered in 1774 to map, survey and strengthen the voids (later any winning has been prohibited within the city limits and no building permit can be delivered without advice from the Quarries Office).

The name of catacombs was given to a part of the quarries, after the bones from the closure of some ancient cemeteries were dumped inside them; this part now is open to visitors. Few other parts have been reused, as the height is rather small (except transient uses in war times). Instead some parts have been filled up, and new infrastructures and buildings are built on masonry walls or piles. Along the river Bièvre (named after beavers), winter ice was stored for use along warmer seasons, and later some breweries stored beer there. Nobody thought at the time that these quarries could be the germ for an underground urbanism to come.

2.2. From Haussmann to Hénard

After many epidemics had been ascribed to lack of hygiene, civil engineer Eugène Belgrand, working under Paris Prefect Hausmann, designed a 600km sewage network of tunnels, big enough to allow for man cleaning and to accommodate the first city utilities, drink water, raw water, cooking gas, compressed air, and later electricity and telephone. Letters and small parcels travelled inside pneumatic tubes under depression, whereas compressed air was used to power public clocks and small machines in mechanics shops and dentists! Since these times, air networks have closed, and the other networks went out, except raw water and some electricity cables, for street lighting and traffic lights. In London about the same years, 160km of sewers were built with smaller cross-sections.

By the turn of the century, architect Hénard (1903 & 1910) designed a two-storey street, *Rue future,* the causeway of which being raised for leaving a space below, dedicated to all utilities; in addition to cables and pipes, narrow gauge tracks served all building basements, mainly to carry coal and ashes, (just as Chicago did at the time). Another sketch from the same author goes farther, with four underground levels accommodating the various traffics under a major street.

2.3. The Paris metro

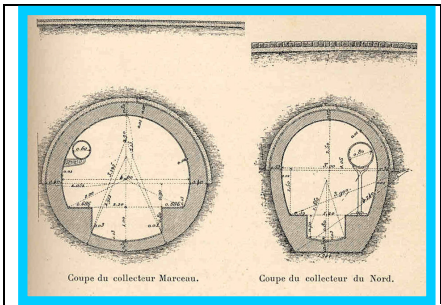
By the end of the century, some of the world biggest cities at the time, of which London and New York, had built underground railways to solve people transportation. In Paris, the first section of metro line n°1 opened in July 1900, followed the same year by two short sections of lines 2 and 6 crossing at *Étoile* Square. The Paris metro is the world densest, and has the lowest ratio of surface tracks; its 14 lines operate on independent tracks (though tunnels unknown from passengers link all tracks together). At the beginning, the relief called for some viaducts along the Circle line (today split in two halves), helping to cross the river on existing bridges; at the time this circle line was outside of the densely built city centre; now train wheels roll on tyres to lower the noise level. Except at *Étoile* station, most of lines have been designed one after the other, crossing one below the other, often with intricate transfer corridors between them. Up to the fifties, no metro line extended out of the city limits. From the sixties on, express lines were added, serving suburbs, often at grade, sections of which sometimes on existing tracks (under name RER, *Réseau Express Régional,* Regional Express network).

At the real business heart of Paris, close to *Saint Lazare* railway station (the Paris first, built 1836), the *Opéra* district also harbours some of the most famous Paris *"Grands Magasins",* so needing a lot of mass transport:

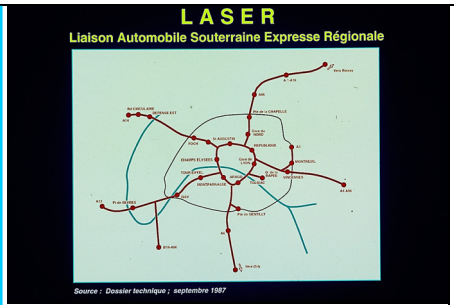
- about one hundred years ago, a three storey station has served three metro lines; it was built inside a big excavation, in front of the theatre;
- in the seventies, the central section of the first A line of RER (Regional Express Metro) had its station built under *Auber* street, the first true underground station with a 25m wide vault, two times more than regular metro stations;
- now, the fifth RER, E line, links the district with the eastern suburbs through eastern railway tracks, waiting for an extension towards *La Défense* and the western suburbs.

All these stations are now connected by underground corridors, from *Saint Lazare* to *Opéra*, and this "underground metro hub" provides direct exits to the basements of the *"Grands Magasins"*.

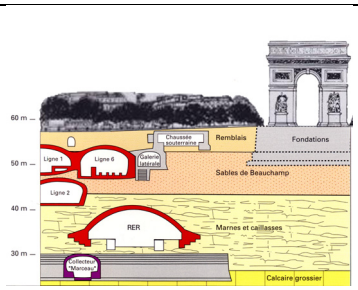
The railway station *Gare de Lyon* serves the whole South-East of France, Lyons and Marseilles, second and third rank cities in France, Grenoble and the Alps, Nice and *Côte d'Azur*, famous resorts for winter and summer sports and leisure. Here the Paris prefect, Maurice Doublet obtained that the RER station be built very close to the national tracks, on two levels for lines A and D, so creating a very efficient hub of rail transportation. Over these tracks, the Ministry of Finance built an office building just on top. By the end of the century, the latest line built is metro n°14, now linking *Saint Lazare* station to the new National Library. Most of its length has been sited inside favourable rock formations, under gravel alluvium and over clays and sands. The Paris Metro Authority, RATP, (*Régie autonome des transports parisiens*) built its new main office building facing the ministry offices, which gave the opportunity to open a window from the station platform to a greenhouse in the basement (up to now the Paris municipality never permitted any light shaft from the street surface inside the metro). A huge car park has been opened on the other side of the railway station, and many bus lines also serve this transportation hub.



Cross section of Belgrand sewers



Scheme of LASER network



Under Étoile Square : 3 metro

man-entry, with pipes and ducts	(GTM) : central ring and 5 radials	stations + RER station

2.4. Édouard Utudjian and the GECUS

After a group of architects and town-planners around Le Corbusier did write the Athens chart, French urbanist Édouard Utudjian named and launched the new concept: *Urbanisme souterrain*. He founded associations and a journal, and began writing papers and books on the theme, including a five volumes encyclopaedia (on underground city-planning). He not only gathered architects, but also engineers and lawyers, in order to build a sound foundation for his ideas. During 40 years, he animated many national and international conferences, the first one in 1937 as a part of *Exposition Universelle* in Paris, the last one in Warsaw in 1975.

He listed many underground achievements as examples, among them a room very few people may have seen, under the central office of the State Bank (*Banque de France*): 25m below the surface, it is a rather square room, area about one hectare, supported by more than 600 concrete pillars; its position below the water table would allow drowning it for protection (excavated 1923). Also underground corridors for the service of luggage below the railway station *Gare de l'Est* which had been rebuilt in 1928. Some high schools, lacking space for expansion, built underground amphitheatres under their courtyards, later followed by Senate and UNESCO, and some others, thanks to windows open around sunken yards, not to mention numerous cinemas, restaurants and night clubs.

GECUS studied and proposed many projects, mostly in Paris, some with the help of famous soil engineer and professor Jean Kérisel, such as a network of underground streets (too early) and a lot of underpasses along main roads, and about sixty underground car parks (all of them have been built since, and even now many more). A project of big warehouse for wine and oil was interesting by its location under Vincennes Park, close to the river and the railway tracks along it, but it was not built. Studies for the Channel Tunnel did not succeed either at this time.

2.5. Les Halles / La Défense / Le Grand Louvre

Les Halles is the first underground complex in Paris: GECUS proposed that two new express metro lines connect at the very heart of the city, about the food market, in order to reduce the street traffic. In 1968, the city decided to seize the opportunity offered by the transfer of the market to Rungis, 13km south. The station to be built was 400m long and 60m wide to accommodate seven tracks and four platforms. The demolition of the market buildings in 1972 (so called *pavillons* Baltard) left a free space big enough to excavate a big hole, 25m deep to locate all tracks and platforms. The RER A (East-West line) opened 1977 and the hole will be filled up by a commercial centre, at a time the biggest one in Europe, taking light from a Forum (a kind of big atrium) inaugurated two years later. A second phase, around *"Place Carrée"* harbours some more shops and mostly culture and sports facilities. The whole area is freed of any traffic as it is crossed by an underground road network, serving many car parks (a network of rather narrow roads, with sharp angles and many bifurcations which made it no longer convenient).

Table 1: Parallel figures on the three big underground projects in Paris

	Les Halles	La Défense	Le Louvre

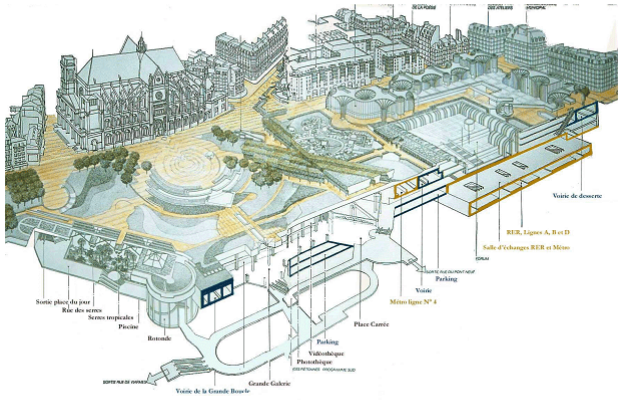
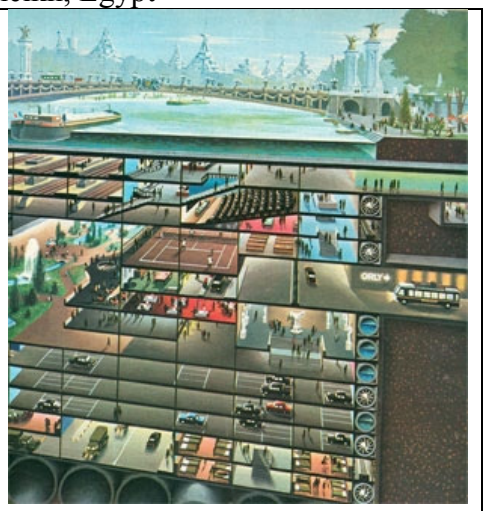
Main aim	Express metro	Business quarter	Access to the museum
Total area	14,8 ha	160 ha	40 ha
Totale depth	30 m	max. 25 m	max. 15 m
Offices	17 400 m²	3 000 000 m²	-
Shops	92 000 m²	210 000 m²	10 000 m²
Car Parks	4 000 places	20 000 places*	600 + 80 bus
Streets	4,2 km	90 000 m²	-
Public Transport	3 RER	SNCF – RER - metro - tram	metro
Number of levels	6	-	-
Greenery	5 ha	11 ha	30 ha
source	Paris Projet 1985	Web site	Web site
		* + 80 000 in private parks	

La Défense is very different (table 1), as its main objective was office buildings, and the site was a hillside, from the Seine quay to the statue on hilltop, which gave its name. It is more a slab quarter with underground roads and car parks, plus a big commercial centre only at the top, between the RER station and the surface. The general axis continues the westward avenues from the Paris centre, followed by RER A, extension of metro nr1, and motorway A14, all underground below the complex, including a road interchange (two thirds of the road surfaces are covered). Now the complex is being extended farther west, up to the river, and the interchange with A86 also is underground. From the RER inauguration in 1970, the construction never ceased and now some of the first buildings have left their place to newer ones. The utilities are gathered into man entry technical galleries (or open voids below the general slab) under supervision of a permanent control room, together with all public spaces, lighting, lifts and escalators, thanks to a *GTC* software (centralised technical management).

Le Grand Louvre also is different: this “great worksite”, engaged by president Mitterrand in 1981, was inaugurated in 1989. The pyramid of architect Ieoh Ming Pei gives light to a central room dispatching the visitors towards main sections of the Museum, and also to the subsurface of *Cour carrée*, where the foundations of the first Louvre castle are made visible (built by King Philippe-Auguste since 1190); but the project goes much farther, encompassing renovation of the buildings, and creation of many underground spaces (amphitheatres, research laboratory on artworks, reserves, together with bars, restaurants and shops). There are no offices, no dwellings, no public roadways, but a direct access from and to the metro station Louvre.

2.6. Rail and road tunnels, up to projects of true underground motorway networks

Transportation through some hilly cities in France benefited rail and road tunnels under hills. Rail tunnels began very early, e.g. a shallow tunnel close to Saint Lazare station in Paris, then on the “little ring tracks” (*Petite Ceinture*). Later rail and road tunnels are bored in all hilly cities, Lyons, Rouen, Le Havre, Marseilles, Nice). In Paris many short underpasses have by-passed important street crossings, and a few longer ones have been established for preservation of the landscape (as along the Louvre museum buildings on the riverside). The concept of a fully integrated network of underground city highways was first issued in the late thirties by Utudjian, too early at the time. In 1988, company GTM (*Grands Travaux de Marseille*) presented a new project under name LASER (*liaison autoroutière souterraine express régionale,* an acronym parallel to RER), with a two level tunnel for light vehicles only, each level one-way; due to the weak support from inhabitants, the mayor of Paris did not follow the proposal.

	
Les Halles underground complex, in front of St Eustache church - right: the Forum over the RER 7 tracks; left the garden over a sport, culture and retail shops	Maymont utopia ? use of the whole subsurface of the river Seine (published 1963 in Paris Match)

Now this concept is used for closing the last section of the second Ring motorway, A86, under a hilly district inhabited by rich people: two tunnels are designed with the same cross section, one for light cars on two levels, the other for all vehicles, one level and bi-directional. A first section of the light car one is yet bored through.

Some years later, company Bouygues proposed a network for the department, *Hauts de Seine* (west of Paris), the richest in the Paris suburbs, under name MUSE (*maille urbaine souterraine express*). The cross section was to accommodate three levels, two for light cars, plus one for mass transit. The network was supposed to be extended later all around Paris and to be well connected to radial highways from the Paris gates.

2.7. Covering the railway tracks

Later, most of the main railway stations of Paris became two storeys, in order to find more tracks for more trains: the underground level serves the local lines, together with RER tracks. It is a good example for any extension of activity within the same surface area.

The biggest development today in Paris is named Paris *Rive Gauche* (left bank, though this name here only applies to the upstream section of this bank). This district was an industrial zone located between the river port of Paris and the railway tracks to the centre and south of France. As the port moved mainly downstream of Paris, a long strip of land was free for redevelopment. In addition, the project designed a wide slab, with a new avenue and the new building for the National Library. So the tracks are now under the slab. The latest metro line 14 crosses this district, a new connecting station being built below the tracks with RER C and metro 14. Previously, the tracks of *Gare Montparnasse* have been covered under a nice garden, with a two-storey car park in between.

3. SOME GENERAL PRINCIPLES OF TODAY

3.1. Four main reasons to go underground

ITA, the International Tunnelling Association, has listed four main beneficial characters of subsurface: i) plenty of extra space is available everywhere, just below, not far from the surface;

ii) underground space provides a high degree of protection and safety against menaces from outside;
iii) provides safe containment for all inside, including nuclear reactors (the only core melt before Chernobyl accident happened into an underground plant without any consequence for mankind);
iv) thanks to Earth opacity, nobody can see what is inside; treasures have been hidden underground since the first ages of mankind.
In other words, subsurface space answers to four needs: need of extra space, the more in the densest city centres; need of hiding all what may be offence to man senses, being ugly, noisy, bad smell; need of protection against view, intrusion, explosion outside; need of containment.

In addition, use of underground space is the only way towards denser cities, and denser cities are the only sustainable cities of tomorrow. The number of inhabitants per unit of area, density, is the first index in city planning:
i) high density allows walking : a dense city is a pedestrian space, where most of needs of mobility may be satisfied by walking a short distance;
ii) high density minimizes the length and the cost of streets, of all transportation systems, and of all smaller utility networks, contrary to what happens in most of suburbs (and cities in North America);
iii) high density saves space for Nature and agriculture, both inside and outside cities.

City utilities give a good example of what could be done: most of them are located underground for various reasons:
i) location below grade to convey used waters through sewers,
ii) frost protection of water ducts,
iii) crossing of streets without interference with the traffic,
iv) aesthetics, against wires and poles along the streets, etc.
But such networks have been installed one after the other without any planning for the future, the first one taking the best location (best for itself only) and the next ones crossing below. Anyone understands that putting all utility networks in common galleries or corridors (in America, utilidors) is a better solution. But many habits oppose such solutions (each authority likes its independence, in contradiction with the general interest). In France a research project has ended with a Guide written for mayors (Clé de Sol, 2005).

The same scheme could apply to bigger networks, as road tunnels, and to bigger plants, as car parks: The LASER project could have been better accepted if it had offered place for mains of other networks, water, electricity, telecom, etc. Any underground car park can offer some more services for shops along the street and inhabitants around: area for car loading and unloading at basement level, protected walkway to next metro station, etc.

3.2. Underground space, the hidden face of any Territory

Any person heard of the hidden face of the Moon; though many people did visit natural caves and grottoes, and many more use rail and road tunnels through the mountains and below the cities, most of people, most of cities, most of states, seem to ignore the treasure their have below their feet. Up to now, the value of subsurface is under recognized, undervalued. Of course, all places do not have equal value; a site likely for such or such underground space use looks like a deposit of such or such mineral. Gold is better than sand; gold content maybe high or low; a gold deposit may be small or large, deep or shallow, close or far. For most of underground space uses, granite is better than clay, sites over water table are better than below, etc. Conversely, sites below water table are good for LPG storage (liquid petroleum gases); thick salt rock deposits are good for storage of noxious products as there is no hazard of water leaching.

The quality of some sites derives from physiography and geology: Hills provide very interesting underground sites, as space inside may be accessed at grade; it is easy to protect from being inundated

and any water seepage may be self drained; going out is likely without energy; difference of altitude may provide self ventilation; air, light, views, orientation may look the same as in conventional buildings. Horizontal bedding of geological formations provides very interesting sites (as in Kansas City). Other favourable sites are given by the type of occupation of the surface: Inside cities, some areas are good candidates for access and use of their underground space, say parks and gardens, barracks, campuses and hospitals, which exhibit large free grounds between their buildings. Airports sterilize very large surfaces around their runways: they could either provide a lot of space below the grass, close to points of high traffic.

3.3. Difficulties and drawbacks: ownership, building codes, hygiene rules

The first problem in many countries derives from laws and regulations which do not take account of underground locations (ownership, city planning and building codes, safety and hygiene, status of working places, etc.). Second are technical problems from ground conditions and the more from groundwater, and associated extra costs (the higher cost of works in the short term, when social benefits are not fully assessed). Third is the lack of image, lacking gratification, either for the landlord or the architect. Geological conditions govern the site; social and legal conditions govern what may be built and how an underground facility may be used.

Along the latin law, followed by a number of countries including France, the private ownership of a land lot extends to a cone or pyramid volume, beginning from the centre of the Earth and infinite towards the heaven. Such definition is no longer valid for air space, which cannot be closed by the tenant and cannot be controlled either, except at the State level. Ownership limits are very restricting inside cities because most of public spaces, say streets, are too narrow to accommodate big underground facilities, and private lots are too small to permit deep excavations. One solution could be to consider the subsurface as a co-property, just as multi flat buildings, the ownership of which is shared by many owners. Kérisel wrote "*A l'ère des mitoyennetés verticales doit succéder une vaste copropriété du tréfonds*" (instead of vertical limits, the whole space must be a common ownership). Another solution is similar to the national rights on the sea: the depth is separated in different slices, under jurisdiction of different bodies, from a private property close to the surface (a general case in many countries) to a central volume similar to open sea, open to all, with equal rights.

Many different codes and regulations apply to buildings (alignment, height, aspect of façades, etc.) most of them disappear underground. In France, in addition to building codes, the hygiene and safety codes forbid any classroom and hospital room under grade level, the working codes demand that any workplace benefits windows opening to fresh air and outside views; some of these rules followed those established for high-rise buildings. The establishments receiving people (ERP) are bound by even more stringent rules: only one underground level (for instance in department stores, museums, etc.) is permitted, and no level may be deeper than 6m; the access for firemen must be different of the ways out of people inside and the capacity of stairs is strictly imposed. Only very big installations can manage such rules and discuss the details with the fire brigade and police authorities; les Halles have served as a laboratory for establishing such rules, which are even tightened after every accident. As usual in many fields, safety standards become harder and harder along time, which is a serious menace on all underground projects).

4. CONCLUSIONS

"Along past centuries, Paris people buried the encumbrances of the city in the depths, so getting out of view all which could be sited underground, whatever for discretion, salubrity, congestion, or aesthetics" This sentence is from Prefect Maurice Doublet asking for a master plan of underground space in Paris (Saletta, 1990).

There is nothing new under sunlight: from Hénard "*Rue future*", through Maymont proposing to use the subsurface of the river (the only free public underground space crossing Paris from east to west), up to many utopian designs from Japan. Let just go on! To make false the formula "Out of sight, out of mind", we all have to think deep.

All which is put underground saves surface space, leaving space for wider streets, for greenery or for more buildings: all things which will enhance the quality of urban life. Only a better use of underground space may make cities of tomorrow sustainable.

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