SENSORS,
NETWORKS,
HACKERS,

THE CITY OF TOMORROW

AND THE
FUTURE OF
URBAN LIFE

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PART III SENSEABLE CITY

Forget the damned motor car
and build the cities for lovers and
friends.
Lewis Mumford, 1979

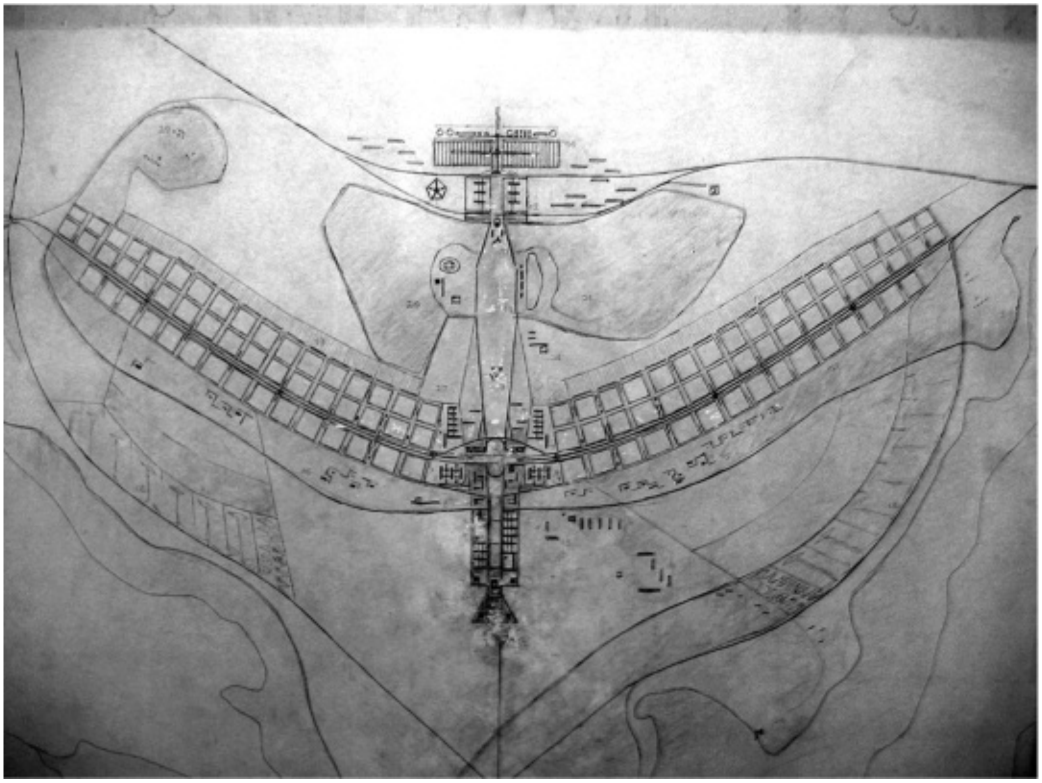
SEVEN

MOBILITY

New cities of the machine age were animated at the speed of cutting-edge contemporary transportation technology: the automobile. Henry Ford's Model T, introduced in 1908, brought automobile ownership to the masses, and as adoption skyrocketed, cars had a profound impact on the fabric of cities. Convoluted networks of medieval or Victorian roads were eventually replaced by gleaming, organized superhighways designed for speeding car traffic. "The automobile is a new development with enormous consequences for the large city. The city is not ready for it . . . I tell you straight: a city made for speed is made for success."[1]

New transportation technology inspired radical visions of a new urban form, not only theoretical but also built. Brasília, a city designed by Oscar Niemeyer and Lúcio Costa and built from scratch, is a striking example of automobile urbanism. Conceived as Brazil's capital, the city was engineered to maximize speed and efficiency (and planned in the shape of an airplane, no less). Various urban elements —banking, hotels, embassies, and government buildings, for example—are kept separate, connected only by a network of highways. Most conspicuously, the city is without sidewalks or traffic lights; instead, intersections are enormous cloverleaf loops. Because there are (in theory) no pedestrians, there is no need for human-scale streets—people move through the city at the speed and scale of the automobile.

Brasília is a rare example of willful urban planning with a singular vision, but automobiles have transformed almost every city in the world—from brand-new, tabula rasa developments to historic city centers. Vehicle ownership increased rapidly in the early twentieth century, and cars quickly became an entrenched component of life and work. Urbanists saw the promise of enriched urban life and dove into a headlong rush to optimize cities for automobiles. In parallel, the increasingly popular car-based lifestyle exerted social, economic, and political forces. Cities were caught in a feedback loop: increased car ownership led to declines in public transit ridership, and simultaneously, policies and funds at the local and national level were diverted away from public transit and toward highways.[2] Citizen behavior spoke clearly: more cars, more asphalt.



Plan of Brasília by Oscar Niemeyer and Lúcio Costa

Building a city entirely from scratch allows the planner to selectively use only the most advanced technology of the time. Recalling the long-standing race for urban efficiency, the masterplanned city of Brasília was designed in 1956 by two Brazilian architects and planners, Oscar Niemeyer and Lúcio Costa. The city is defined by state-of-the-art transportation technology—the automobile. (Seen from above, however, Brasília looks like an airplane.) Car culture dominates in a city composed almost entirely of highways. The original plan, shown here, contains no sidewalks or traffic lights, and different urban functions are separated into distant zones. The city is an important political and economic center, but it is almost without character or life, earning the city its nickname "ilha da fantasia," or fantasy island, in Portuguese.

Schemes that targeted public transit exacerbated societal shifts toward personal mobility. What has come to be known as the "Great American Streetcar Conspiracy"—although the conspiracy remains unproven—choked public transit in cities across the United States during the 1940s and 1950s. A group of automobile companies, allegedly led by General Motors, implemented programs to purchase streetcar and electric train systems and subsequently dismantle them. The project was brought to the public spotlight by a whistleblower, Commander Edwin J. Quinby, in 1946, with accusations that there was a deliberate scheme to shift the United States toward automobile dependency. Although the companies were never legally prosecuted under antitrust regulations, the affair unambiguously contributed to the same vicious cycle: cities became increasingly hostile to pedestrians, and cars became increasingly necessary.[3]

The automobile became a symbol of the American dream, embodying success, individualism, and empowerment. A personal vehicle could satisfy any whim or fancy—unfettered by train schedules or bus routes, cars promised mastery of space and time. The allure of the automobile, particularly in mid-century America, was nothing short of pure freedom. The same attitude rapidly permeated—to varying degrees—most of the industrially developed and emerging world.

In almost perfect synchrony with the rise of automobile glamor Los Angeles sprang up out of the Southern California desert. With seemingly limitless space and wealth to match, the city spread itself from the ocean in the west to the Inland Empire in the east, resulting in a distinctive and disaggregated urban form. The pattern was so characteristic that the urbanist and architectural critic Reyner Banham made a pilgrimage from the United Kingdom to define and study it. He sought to understand not the signature buildings of the city but the urban fabric and its genesis—and to do that, he took to the roads. “Like earlier generations of English intellectuals who taught themselves Italian in order to read Dante in the original,” said Banham in a colorful documentary, “I learned to drive in order to read Los Angeles in the original.” What he found outside the windows of his car was a city built of four “ecologies”: Surfurbia (the beach), Autopia (the freeways), the Plains of Id (the flatlands), and the Foothills. “The point about this giant city, which has grown almost simultaneously all over, is that all its parts are equal and equally accessible from all other parts at once.”[4] Rather than a traditionally centric and radial urban form, Los Angeles spread in a cellular and vascular way, with each area interconnected through a tissue of road networks. In a society where everyone owns a car, every point is connected with every other, and the intervening space is irrelevant.

The extraordinary thrust of automobile optimism arced through the first half of the twentieth century, but momentum inevitably waned. It became clear that unbridled car-focused urban development would have severe negative consequences. Another feedback loop had taken hold: the answer to more traffic is more roads, which, in turn, invite more traffic. Urban spaces spiraled out into sprawling suburbias that depended on the life support system of automobiles. The pattern was quantitatively described by the law of peak-hour expressway congestion, which mathematically demonstrates that “on urban commuter expressways, peak-hour traffic congestion rises to meet maximum capacity.”[5] It follows, logically and empirically, that increasing road capacity can make traffic congestion worse, in addition to stifling public transportation:

> Almost before the first day’s tolls on these expressways have been counted, the new roads themselves are overcrowded. So a clamor arises to create other similar arterials and to provide more parking garages in the center of our metropolises; and the generous provision of these facilities expands the cycle of congestion, without any promise of relief until a terminal point when all the business and industry that originally gave rise to the congestion move out of the city, to escape strangulation, leaving a waste of expressways and garages behind them.[6]

Automobiles nonetheless continued to define the twentieth-century urban development paradigm. With a goal of maximum traffic throughput, new highways cut through the built environment and fueled metropolitan sprawl. Consistent and passionate critics of suburbanizations, most vocally Lewis Mumford, held planners accountable, starting in the 1960s. Among Mumford’s less subtle arguments is the iconic phrase “Forget the damned motor car and build cities for lovers and friends.”

And yet, even today, urban spaces around the world continue to develop in the image of the American city. Urban planning is defined by car culture, and the resulting urban systems present few transportation alternatives. In some cases, the scale and severity of congestion are entirely unprecedented. In 2010, Beijing—a city notorious for its overcrowded ring roads—saw the longest recorded traffic jam in history: a blockage not caused by accidents, closures, or natural disaster but by the sheer number of cars on the road. At one point the stoppage reportedly stretched for sixty-two miles and incapacitated the highway for more than twelve days.

Traffic congestion has implications beyond throughput and delay. As cars idle, they continue to emit pollutants, releasing a maximum level of toxic emissions when they accelerate from a standstill. Crowded roads can cause acute spikes in smog, a pattern that is further exacerbated by certain geographic and atmospheric conditions: valleys that collect air, stifling summer heat, deep canyons between skyscrapers, lack of wind. A 2014 report from the World Health Organization states: “Few risks have greater impact on global health today than air pollution: the evidence signals the need for concerted action to clean up the air we all breathe.” WHO estimates that every year poor air quality causes seven million premature deaths.[7]

The impact of automobiles resonates in a variety of less obvious ways as well—for example, parking. A high number of cars within city limits requires a proportional volume of parking infrastructure, and cities tend to naturally adjust the number of spots to satisfy peak demand. Parking availability escalates in much the same way as freeway capacity (demand rises to meet—and strain—supply). This situation has inspired compelling arguments against the unquestioned addition of parking infrastructure.

> Urban planners typically set minimum parking requirements to meet the peak demand for parking at each land use, without considering either the price motorists pay for parking or the cost of providing the required parking spaces. By reducing the market price of parking, minimum parking requirements provide subsidies that inflate parking demand, and this inflated demand is then used to set minimum parking requirements. When considered as an impact fee, minimum parking requirements can increase development costs by more than 10 times the impact fees for all other public purposes combined. Eliminating minimum parking requirements would reduce the cost of urban development, improve urban design, reduce automobile dependency, and restrain urban sprawl.[8]

The public health threat of pollution and the infrastructural burden of parking are reaching broader awareness, but automobiles also have a less quantifiable impact on urban form and quality of life. Despite the best intentions of early planners, automobile-centric transportation systems, particularly at their present scale, are insensitive to the subtleties of urban space and, at worst, destroy the fabric of the city.

The answer to urban expansion and diffusion—and the host of social consequences that they bring—may be to optimize, rather than increase, transportation infrastructure. A first wave of developments started at the turn of the millennium, drawing on digital and physical systems. Top-down systemic engineering has been proven effective for achieving efficiencies in several cases around the world. Notably successful examples are electronic road pricing and flexible office hours. The first is similar to economic incentive programs that flatten peak energy loads by making power more expensive when it is in high demand: when roads are crowded with commuters, the system responds by charging them more, effectively mitigating peak congestion. Various forms of Electronic Road Pricing have been implemented by cities around the world, including London, Singapore, Stockholm, and Milan, improving traffic in their downtown road networks. With similar intent, many corporations have introduced offset working hours to shift commute times earlier or later without impacting the duration of the workday.

There is also a bottom-up or decentralized response to readapting the network, one that instrumentalizes the existing infrastructure in an opportunistic way. Cars are idle approximately 95 percent of the time, making them an ideal resource for a sharing economy.[9] It has been estimated that every shared car can remove between ten and thirty privately owned cars from the road.[10] Zipcar, for example, puts a fleet of shared cars into the hands of a subscription-based community. Rather than each person owning a vehicle—using it perhaps twice a day and leaving it parked for the remaining twenty-three hours—a much smaller number of communal cars can satisfy the overall mobility demand.

Even more distributed peer-to-peer systems might emerge that allow the ride itself to be shared. Using a large dataset from taxi networks, a team of researchers at the Senseable City Lab has examined the potential impact of sharing car trips. They found that the mobility demand in several different global cities could be satisfied by only 40 percent of the cabs in service today.[11] Although the project developed a new mathematical model for “shareability networks,” it was ultimately an act of design and futurecraft—imagining a future condition of widespread sharing, demonstrating the impact on vehicle use, and making the results available to the public—with the intent of opening possible avenues for development. Online platforms for networking and real-time data analytics could make this an immediate reality, connecting passengers and enabling trip sharing to radically transform urban mobility.

HubCab by the MIT Senseable City Laboratory

The sharing economy is making inroads in transportation. More and more systems allow people to share cars: some are publicly funded, such as BlueIndy in Indianapolis, and others are based on private subscription services, such as Zipcar. Yet with pervasively networked platforms and real-time analytics, people may also be able to share individual rides. This simple hypothesis was the futurecraft scenario for a project called HubCab by the Senseable City Lab. A team of researchers created a mathematical model to determine the potential impact of ride sharing and applied it to a large dataset from New York City's taxi network. Shown here is a visualization of that dataset—all the taxi pickups and dropoffs in the New York area over the course of a year. Mathematical analysis demonstrates that 95 percent of trips can be shared and that the entire city's mobility demand could be satisfied by only 40 percent of the cabs in service today. The same numbers hold true for several different cities around the world and point to a near future in which innovative systems can cut travel time, costs, emissions, and traffic on our roads.

Such systems are dependent on local conditions, urban form, and social structures—for example, sharing systems would necessarily be very different in rural agrarian communities—but overarching trends are nonetheless evident. Even in sprawling suburban areas, real-time information can make public or shared transportation feasible, with algorithmically optimized mobility on demand. It would not be effective to plan a traditional bus route to a sparse community, but car or van sharing with real-time synchronization could be a viable option. Digital platforms stand to reactivate suburban areas and stymie the problematic feedback loop between cars, urban form, and social norms.

A host of emerging technologies are adding momentum to this trend. One advance that draws on sharing networks, data analytics, and hardware developments is self-driving cars. Autonomous mobility may be the final nail in the coffin of the individualist mobility paradigm, bringing the death of car culture but a rebirth of the (new) car.

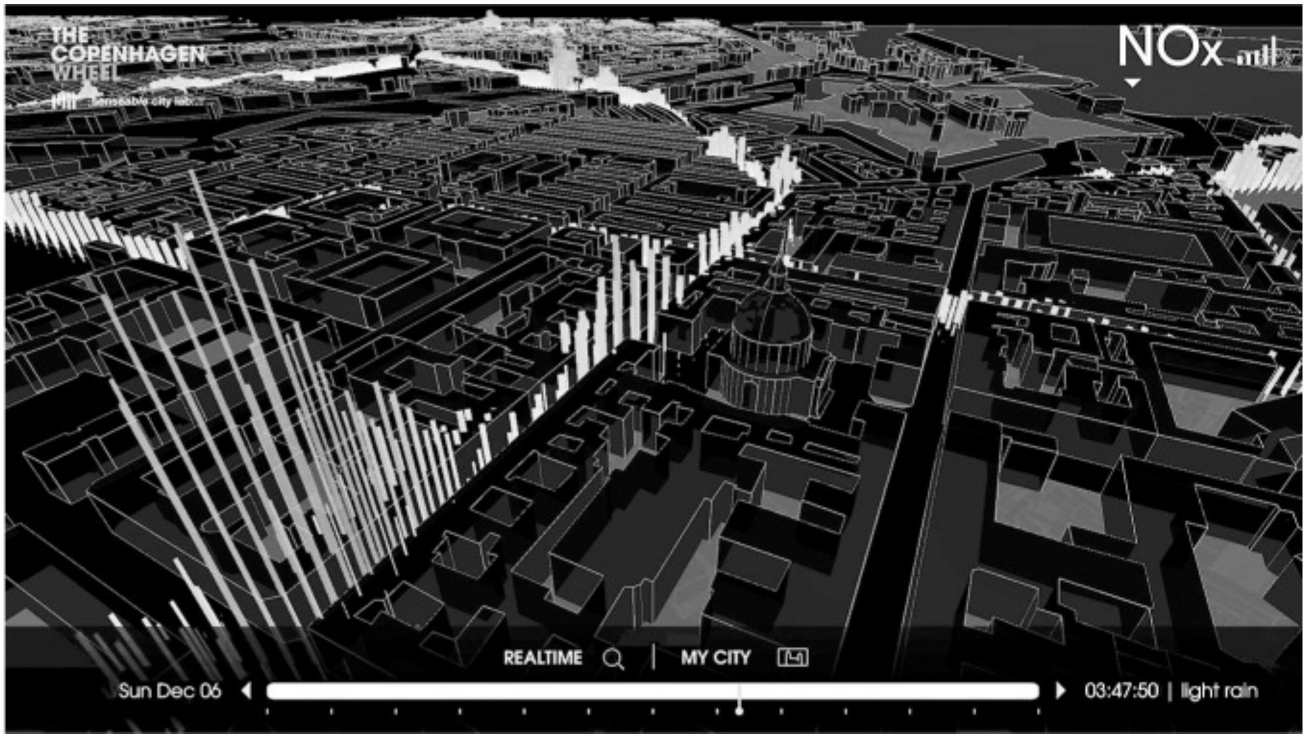
The imminent generation of self-driving vehicles could be programmed according to a variety of different criteria, for example, comfort, fuel efficiency, or shareability. Self-driving could have tremendous impact at the urban scale, where telemetry and big data analytics might optimize vehicular flows through the city. Autonomous vehicles may prompt another wave of innovation in urban systems, from smart intersection management to procedures for dynamically rebalancing the vehicle network according to demand. For example, cars could autonomously migrate toward business centers at the end of the workday, preempting an increase in trip requests. As vehicles are increasingly shared, four out of five cars could be taken off the roads, and the remaining ones could be used in a more efficient way.[12]

The propagation of a new kind of urban infrastructure—silicon rather than asphalt—is eroding the symbolism of empowerment and emancipation that personal automobiles once carried. Previous attempts to reorient urban planning away from automobiles failed—not for lack of effort or sophistication but because the car was still firmly entrenched in daily life and culture.

A sea change is occurring today: the car no longer represents liberation. Individuals are empowered instead by a broad “transportation portfolio,” a menu of options based on real-time information platforms that will ultimately enable a new regime of “ambient mobility.” Personal transportation options are increasing in availability and sophistication, with an emphasis on shareability. Many cities around the world have city-bike and city-car systems, allowing visitors or residents to use a vehicle for a short period of time. An ambient mobility portfolio could also be tied to a constellation of external factors, from ecological footprint to personal health, including walking, running, or biking. Smart electric hybrid motors transform the bicycling experience and bring it online, while personal activity trackers show miles run, walked, or biked.

The freedom to choose between bicycling, sharing a car, walking, taking an on-demand taxi, using the subway or train, and hitching a ride with friends is far more appealing than owning and maintaining a car: it puts agency back into the hands of individuals. The trend is already apparent in drivers’ license statistics—the percentage of young drivers obtaining licenses is diminishing sharply in the United States.[13] Generation Y has found a new way of using the asphalt laid by their parents.

A broader mix of mobility options can also increase efficiency, as the plurality of options allows the system to naturally balance itself. When information is delivered in real time—for example, “The bus is crowded and running slowly, so why not try a bike?”—individuals can make informed decisions, with a net positive effect. Not only will this activate unused capacity in the transportation network, but additionally, it will empower the population to behave based on an understanding of the impact of each decision on overall urban function.



Copenhagen Wheel by the MIT Senseable City Laboratory and Superpedestrian

For decades, cars have ruled the city, but a new generation of smart, networked transportation devices is taking hold. In addition to satisfying the urban mobility demand, these technologies can stream real-time information about the city and its environment. The Copenhagen Wheel transforms any ordinary bicycle into a smart electric hybrid. The red casing contains a motor, batteries, sensors, wireless connectivity, and an embedded control system. The wheel senses and learns how you pedal and integrates seamlessly with your motion, multiplying your pedal power between three and ten times. An array of onboard environmental sensors constantly collects data such as air quality measures, noise level, and traffic and routing information. Pictured is a visualization of data from an initial deployment of the wheel in Copenhagen.

As ambient mobility platforms are widely adopted, public and private mobility paradigms will blur. What was formerly a clear (functional and social) delineation between shared and individual modes of transit will be erased. “Your” autonomous car can drive you to work and then drive someone else to school, rather than sitting idle in a parking lot all day. A single vehicle will go from one hour of use per day to twenty-four hours of use, as it is shared among a nuclear family, friends in a social network, a neighborhood, or an entire city.

Just as a small group of people might share an apartment, they might also share a set of mobility options. Social connectivity will become a key component of transportation strategies, aligning the number of vehicles with the number of travelers. This new structure will be compounded with improved intermodality, with the use of real-time information to streamline the transfer from one transportation system to another. Ambient mobility offers will integrate seamlessly, to the point of omni-modality. Commuters may bike to the station just in time to catch a train, and alight to find an autonomous car waiting for them at the station, ready to drive the last mile. Welcome to the age of the transportation portfolio.

The fireside circle could no longer
serve as social glue. The old social
fabric—tied together by enforced
commonalities of location and
schedule—no longer coheres.
What shall replace it?
William J. Mitchell, 2000

EIGHT

ENERGY

The earliest form of habitation technology was the grotto—a natural feature that humans sought out for warmth, protection, and sociability—and there they built the primordial hearth. Nomadic hunter-gatherer culture transitioned to a stable society, coalescing around the fire pit's climate control system. For both sociability and efficiency, shelter developed according to a centralized model. The hearth was a focal point of social space—as the architect Frank Lloyd Wright famously noted, it is the "psychological center of the home."

Yet as time progressed, architecture's many dimensions became decentralized, following an outward trajectory of spatial liberation. What was once a circle of firelight fractured into a proliferation of light fixtures in every room; the village well, formerly a site of gathering and gossip, flowed out through pipes to each home; even entertainment crossed the threshold of the theater and was beamed to cathode-ray tubes and screens in every living room. Elements of habitation are now individually and instantaneously delivered. Life is unmoored.

Climate control is no different—with the evolution of the hearth, heat was progressively liberated. Over time, humans exerted increasing control over temperature, until the "enforced commonalities of location and schedule" began to fray.[1] The Victorian era brought heat to homes, through pipes that circulated hot water. Each room could be temperature-controlled using iron radiators. The triumph of centralized domestic heat, half a century later, was the thermostat, a simple system that maintains a stable temperature at the desired setpoint by sensing ambient air and automatically turning central heating on or off.

Atomization, however, comes at the cost of efficiency—particularly in the case of climate control. The hearth is no longer a shared resource that attracts people but a distributed system in which each user demands the right to comfort at all times. With central heating and a binary on-off system, there has come to be a dramatic asymmetry between human occupancy and energy use. Entire homes are heated during the day when residents are at work or school, and even when they are home, empty corners of the house are indiscriminately kept just as warm as those in active use. To ensure constant comfort, we heat every space we might possibly inhabit.

Architecture could be conceptually reduced to a functional assemblage of environmental life-support technologies. Reyner Banham's 1965 essay "A Home Is Not a House" took a critical stance toward the modern domestic situation, suggesting a dissociation between environmental support and architecture. The essay begins with an incisive question: “When your house contains such a complex of piping, flues, ducts, wires, lights, inlets, outlets, ovens, sinks, refuse disposers, hi-fi reverberators, antennae, conduits, freezers, heaters—when it contains so many services that the hardware could stand up by itself without any assistance from the house, why have a house to hold it up?”[2] The project highlights our modern dependence on climate control technologies and the obsolescence of both social and natural environments. An image titled *Un-House Transportable Standard-of-Living Package* shows Banham and Dallegret sitting naked in a transparent “Environment Bubble” on either side of an air-conditioning unit.

The thermostat was invented to keep a constant ambient temperature at the user’s discretion—and Banham called out the proliferation of such technologies and our concomitant dependence on them. Recent digitization, however, allows feedback systems that dynamically manage climate and allow technology to fall into the background without radically subverting the premise of architecture. Research shows that modulating energy usage based on occupancy could reduce consumption dramatically—in the case of the United States, by almost one-third.[3] One of the earliest devices, aptly named Nest, integrates smartphones with the home heating system. The digital thermostat learns from its users’ daily habits, can be controlled remotely, and encourages various environmentally beneficial patterns, including some that are based on gamification and promote playful family dynamics. The evolved thermostat works together with occupants to optimize climate systems.

Nest dynamically adjusts temperature over time, but the next step could be a similar degree of control over space—that is, synchronizing heat with residents’ physical location. In a future scenario of architecture that senses and responds, a dynamic system for *local warming* could enable fine-grained control over personal climates while simultaneously improving energy efficiency.[4] Using sophisticated motion tracking paired with dynamic heat emitters, an individual thermal “cloud” would follow each human throughout a building, ensuring constant comfort while minimizing overall heat requirements. “Man no longers seek heat . . . heat seeks man.”

Sensor networks integrated with fine-grained response systems are beginning to save energy across a broad spectrum of habitation systems, not only climate control systems. In addition to directing energy where and when it is needed, the trajectory toward sustainability is progressing in another way: mitigating peak loads.

Past and Future of the Thermostat: Examples from Nest and Honeywell Labs

The traditional thermostat, such as the iconic Honeywell dial depicted, maintains a constant temperature at the users’ discretion, but at the expense of efficiency. Entire homes or offices are kept comfortable, even if they are entirely or partially empty. Yet digital integration is causing rapid transformations in climate control technology. Nest represents the next generation of home climate system, one that aligns heat with daily and seasonal rhythms. It self-adjusts and builds personalized schedules by integrating directly with smartphones—even warming up a home before its residents arrive if they decide to come home earlier than usual. A digital control system dynamically modulates temperature based on the patterns it learns from occupants, improving overall energy efficiency.

City dwellers tend to demand energy at the same time (for example, at 7 p.m.), so to ensure that lights illuminate when any person (or every person) flips a switch, power plants must constantly produce enough energy to satisfy the maximum possible demand. Pattern analysis and predictive models can help align supply to demand, but even so, it is difficult for plants to tailor production effectively.

Local Warming by the MIT Senseable City Laboratory

A staggering amount of energy is wasted on heating offices, homes, and partially occupied buildings. Energy is used to change the temperature of empty air, rather than the temperature of people themselves. Local Warming addresses this asymmetry by synchronizing climate control with humans. Responsive infrared heating elements, guided by sophisticated motion-tracking sensors, are mounted around a room. These emitters can transmit collimated heat to create a precise personal (and personalized) climate for each occupant. Individual thermal clouds follow people through space, ensuring constant comfort while dramatically reducing overall energy use. Pictured is an early prototype of Local Warming.

In 1981, Buckminster Fuller put forward the radical concept of a Global Energy Grid, a worldwide system of electroducts for international energy transfer. This would enable different countries to balance each other’s supply and demand: when Europe is demanding energy during the day, China is asleep, and vice versa.[5] Furthermore, at any given moment, one side of the globe is facing the sun and could potentially be harvesting solar energy. In theory, the Global Energy Grid would send power from the sunny regions with surplus energy to dark regions with a deficit. The crux of Fuller’s plan was reducing variations in the global system: mitigating the peaks and valleys. Fuller summarized the concept in characteristically sweeping terms:

> I have summarized my discovery of the option of humanity to become omni-economically and sustainably successful on our planet while phasing out forever all use of fossil fuels and atomic energy generation other than the Sun. I have presented my plan for using our

> increasing technical ability to construct high-voltage, superconductive transmission lines and implement an around-the-world electrical energy grid integrating the daytime and nighttime hemispheres, thus swiftly increasing the operating capacity of the world's electrical energy system and, concomitantly, living standard in an unprecedented feat of international cooperation.

Global demand would dictate energy transfer, sparking what Fuller believed would be a shift of the economic standard from gold to kilowatt hours. "Such intercontinental network integration would overnight double the already-installed and in-use electric power generating capacity of our Planet," Fuller concluded.[6] The idea carried remarkable implications for sustainability, economy, and society.

Although the idea of a global superconductor network is alluring, it remains technologically and financially challenging. However, optimizing existing systems from the individual to the urban scale might achieve similar ends. Today, built environments are beginning to dynamically respond to humans in real time using sensing and actuating feedback loops. These responsive digital systems may control energy generation, demand, and distribution. The behavior of these dynamic systems "changes over time, often in response to external stimulation or forcing." The term "feedback" refers to "a situation in which two (or more) dynamical systems are connected together such that each system influences the other and their dynamics are thus strongly coupled."[7] As these systems blanket our cities, every dimension of habitation can be transformed, from the simplest example, occupancy-sensing lights in a single room, to complex systems for sensing, modulating, and optimizing energy patterns across an entire city.

According to the United States Department of Energy, "We are stretching the patchwork nature [of the existing electric grid] to its capacity. To move forward, we need a new kind of electric grid, one that is built from the bottom up to handle the ground-swell of digital and computerized equipment and technology dependent on it—and one that can automate and manage the increasing complexity and needs of electricity in the 21st Century."[8] This is the promise of the *smart grid*.

In a very basic sense, the smart grid is simply an introduction of dynamic control systems for energy production, distribution, and consumption. The concept is rooted in an infrastructural framework of distributed (preferably renewable) energy production. With an integrated digital control system at the neighborhood or regional level, each house could generate energy and share surplus with others nearby or store it in local batteries. Today's archaic energy-switching technology will transition to a digitally controlled system, allowing faster response to real-time conditions.

Smart devices for end users can dynamically configure their consumption patterns based on information from the grid—a refrigerator, for example, can cool when energy is inexpensive and cycle off during peak demand. But the system is not exclusively automated top-down control. It also enables bottom-up incentivized response. Networked smart meters stream real-time information, monitor local and regional demand, and offer incentives directly to users. Surge pricing—that is, pricing that changes in response to demand—provides a financial incentive for users to conserve resources. Individuals are free to make decisions and can do so with the knowledge of overall energy demand. In more domestic terms: your refrigerator might automatically adjust its on-off cycles for efficiency, but running the dishwasher or charging a computer are still individual choices. Smart meters can inform real-time dynamic pricing so that people are free to use power however they want, but when demand is high, the cost will rise. By whatever means, the goal of the smart grid is to mitigate and level out peaks in demand and to reduce the amount of power generation required.

A truly functional smart grid is still quite far in the future, yet it is already possible to implement more efficient energy systems. The likely interim step will be a hybrid system situated between local and regional production, one that incorporates a wide array of urban infrastructures, from architectural batteries to systems for using cars as accumulators. Efficiency will be achieved by centralized distribution systems, optimized by responsive feedback loops, and incrementally supplemented with organically growing local production and consumption networks. If the two can balance dynamically, the marriage of complementary systems would allow for large centralized energy harvesting to fill in the gaps of local production grids.

This points to a future in which the overall energy infrastructure is dynamically managed, as each kilowatt-hour package is tagged and carries a variable price based on real-time supply and demand. Energy will be directed and delivered with intention, precisely where it is needed. In a near future, every device—and every vehicle and every building—will transfer energy in and out, constantly communicating with the broader network to balance overall system flows. Energy supply will respond to demand: the network itself will mitigate peaks and dips as it interacts with human dynamics.

The factory of the future will focus
on mass customisation—and
may look more like those weavers'
cottages than Ford's assembly
line.
Paul Markillie, 2012

NINE

KNOWLEDGE

The first industrial revolution profoundly reconfigured society. Beginning with Britain's iron and textile industries, innovations in factory procedures and powered machine technology sparked mass production. The shift from hand to machine fabrication brought about a profusion of factories, which, in turn, required an expanded laborer class. A host of unskilled workers executed highly specific tasks in the long chain of fabrication while a small demographic of intelligentsia orchestrated the process, and an even smaller elite reaped the benefits of the system.

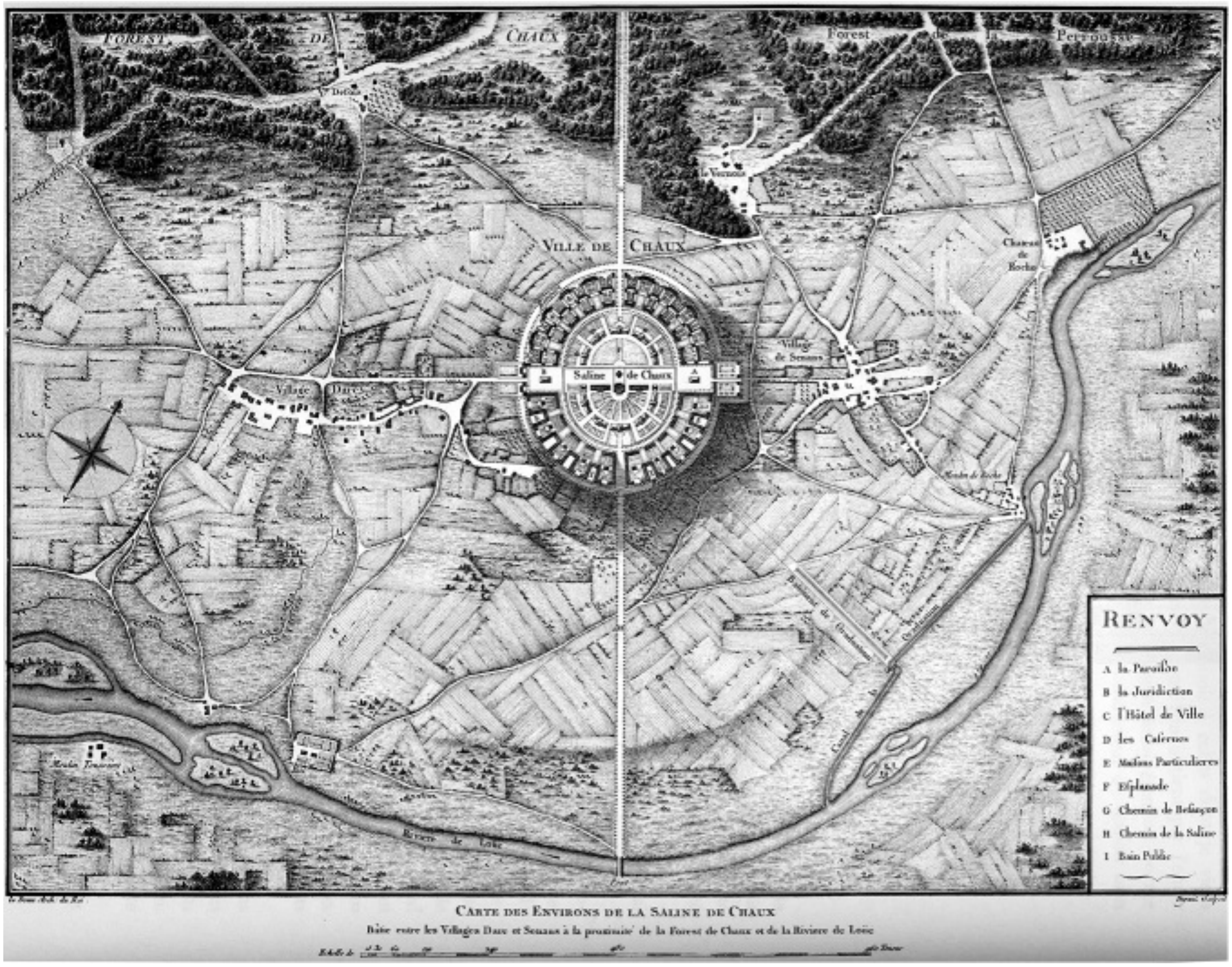
There was a sharp demarcation between productive (repetitive) and intellectual (creative) work, "a transmuted form of the barbarian distinction between exploit and drudgery," so to speak.[1] People were reduced to functional components of a larger system that was itself mechanical: countless hands hovering over conveyor belts executing repetitive tasks in identical factories for endless hours.

The significance of individuals and their talents diminished as humanity acquired value only in numbers. Lewis Mumford offered an incisive summary: "We have created an industrial order geared to automatism, where feeble-mindedness, native or acquired, is necessary for docile productivity in the factory; and where a pervasive neurosis is the final gift of the meaningless life that issues forth at the other end . . . By his very success in inventing labor-saving devices, modern man has manufactured an abyss of boredom that only the privileged classes in earlier civilizations have ever fathomed."[2]

Not only did the industrial revolution reshape social structure, it also radically respatialized cities. Prior to the late eighteenth century, craft production took place in the residential workshops of fairly isolated villages. But as society shifted its gears for maximum output, the formerly agrarian population flooded into cities, looking for work. A new urban typology emerged: cities expanded into distinct zones for production (factories) and habitation (mass housing). The influx of workers exceeded the rate of expansion, and in crowded centers such as London, Manchester, and Birmingham, conditions for the working class were dismal.

The challenge of spatial optimization for production and housing inspired some early experimentation with entirely new factory towns in the years preceding the industrial era. These were engineered as meticulously as the production lines they hosted, which were optimized for throughput. One of the archetypes of the master-planned city from the proto-industrial era was the French Royal Saltworks at Arc-et-Senans, by Claude Nicolas Ledoux. In both organization and decoration, the saltworks complex expressed the supremacy of human rationality: drawing on ideas about the natural structure of the universe and geometric mathematics, the Royal Saltworks were a crystallization of contemporary French society on the brink of industrialization. Architecture was at once physics and metaphysics, orchestrated for production. The plan, for example, is a hemisphere, representing geometric purity as well as providing optimal visual access to the overseer and maximizing the number of living units with direct access to work areas. Ledoux understood the facility as two interdependent systems and two geometries: the administrative directorship, including the overseer and the tax agents, was organized linearly on the diameter of the hemisphere, and the workers' housing was arrayed radially on the perimeter.

The project was followed by a host of similar production-cities. Urban form was a spatial expression of the output-oriented social structure. The epoch's momentum continued, and "la ville fonctionelle" reached a pinnacle of spatial orchestration at the merger of architecture, labor, and society. State-of-the-art transportation systems were imagined to link single-use urban zones for labor, habitation, and leisure. These functional utopias were designed to raise the standard of living for each employee while maintaining maximum productivity.



Royal Saltworks at Arc-et-Senans by Claude Nicolas Ledoux, 1775–79

There is a long tradition of using spatial planning, at the architecture, campus, or urban scale, to promote mechanistic productivity. The French Royal Saltworks at Arc-et-Senans were master-planned in the 1770s as an expression of both social and functional ideals. The plan, shown here, reflects Enlightenment-era philosophy—the geometric position of humans in the cosmos and the relationship between overseers and employees—and the emerging economic reality of the factory city. Different elements were arranged to optimize the workers' daily tasks and reinforce the factory's human hierarchy. The campus was an expression of contemporary French society: the triumph of rationality and an economy poised for industrialization.

This mechanistic approach to urban form was a continuation, even an expression, of the industrial-era labor mentality. As manufacturing technology became increasingly sophisticated, the pace and precision of fabrication processes rose ever higher. The entrepreneur and inventor Henry Ford—a key figure of the so-called second industrial revolution—orchestrated meticulous production lines for low-cost, high-output fabrication. The epochal Ford automobile facilities churned out cars at an unprecedented rate: one every three minutes. The new methods increased production eightfold, reducing the number of labor-hours per car from about 12.5 to 1.5. Le Corbusier visited the Detroit factory and was so impressed by its streamlined operations—by what was considered to be the future of fabrication, industry, and architecture—that he reportedly exclaimed, “I am immersed in a type of astonishment!”[3]

Despite advances in machine technology and procedural configurations, however, humans were still chained to the factory line. Throughput skyrocketed, ushering in the era of mass production, yet working conditions were still defined by long hours, physical danger, low wages, and repetitive tasks.

At that time, the vision of ideal production was a future in which humans—prone to errors, delays, and strikes—were incrementally engineered out of the factory line and replaced by automation. The idea that “Mechanization Takes Command” (a phrase coined as the title of an iconic book of the time) proposed a new kind of interaction between man and machine. That is, “the problem of the assembly line is solved when the worker no longer has to substitute for any movement of the machine, but simply assists production as a watcher and tester.”[4] With a series of technical innovations, manual tasks could be left to machines, and human labor could shift away from monotonous repetition—or even cease altogether.

Complete automation could, theoretically, relieve humanity of all labor obligations, triggering a societal shift from production to play. The term *Homo Ludens*, coined by the cultural historian Johan Huizinga in 1939, refers to this hypothetical phase in social evolution. “Modern fashion inclines to designate our species as Homo Faber: Man the Maker . . . It seems to me that next to Homo Faber, and perhaps on the same level as Homo Sapiens, Homo Ludens, Man the Player, deserves a place in our nomenclature.”[5] Play (as distinct from work) can be understood as the primary impetus and expression of human culture, the force that creates and animates society. If fabrication and production are outsourced to machines—and adequate equity measures govern access and control of technology—then play could be the last and greatest human activity.

Since the beginning, humans have had to occupy themselves with survival, but some theorists have imagined that the demands of time and effort could diminish and even vanish. This shift would have an even more transformative—and diametrically opposed—impact on society than the industrial revolution. The Dutch artist Constant Nieuwenhuys based New Babylon—a decades-long project for social, aesthetic, and urbanistic exploration—on this premise. “The opposite of utilitarian society is ludic society, where the human being, freed by automation from productive work, is at least in a position to develop his creativity . . . it is clear that a ludic society can only be a classless society. Social justice is no guarantee of freedom, or creativity, which is the realization of freedom. Freedom depends not only on the social structure, but also on productivity; and the increase in productivity depends on technology. ‘Ludic society’ is in this sense a new concept.”[6]

Though grounded in very real technological developments, Constant’s New Babylon and other such projects offered a speculative future that failed to materialize. Yet the widespread adoption of digital fabrication technology is restructuring production in different ways—spatially, procedurally, and socially. These developments have been branded with an iconic label: the third industrial revolution.[7]

Three main transformations are taking place. First is the possibility of creating material forms through digitally controlled additive processes—that is, by laying precise deposits of material to build up a shape

—using 3D printers. Not only does this allow for much more complex geometries than have ever been possible, but it also shatters the established laws of mass production and economies of scale. Industrial-era factories churned out large quantities of identical objects, reducing cost through repetition. According to that model, a bespoke item—say, a customized Rolls-Royce—was extremely expensive. For 3D printing and digital fabrication, on the other hand, there is effectively no difference between creating identical versus unique objects. Items can be manufactured for about the same cost, whether by the thousands, by the hundreds, or for a single unit. This is a complete reversal of the Fordist factory lines that churned out identical products according to the mantra "You can have any color car, as long as it is black." Digital fabrication will usher in an era defined by individual control. "The factory of the future will focus on mass customisation—and may look more like those weavers' cottages than Ford's assembly line."

The second transformation is the possibility of fluent transition from digital outputs to physical objects. Thanks to subtractive CNC machines (computer-controlled machines for drilling, cutting, carving, and more), and additive 3D printers, digital code can become physical material or action with a click. In much the same way as personal printers allowed people to create documents in their homes, the production of *things* is quickly becoming customizable and immediate. As the boundary between software and hardware is blurred, custom fabrication will be carried out on demand. The act of making objects will become more like compiling and executing code than like laborious, specialized, and time-intensive woodcraft in a carpentry studio.

The third transformation—a result of the fluency between digital and physical—will be social. Using intuitive software, anyone can create and upload a design online to be shared with friends, communities, or the public at large. Just as in open software, a project itself could spark new modes of collaboration between a variety of actors. The architect David Benjamin writes, "It's much easier to use [digital] tools and the equipment is cheaper, so the projects are getting more interesting. But most importantly, the community around these projects has grown: people do a project, publish their process and results, and then other people ask questions about how it was done and discuss the project. Once there's that community of people sharing projects with an open source ethos, that's kind of unstoppable. It's not really the technical stuff; it's the social stuff."[8] A marketplace of downloadable and printable objects could displace or redefine professional designers through an alternate economy driven by either financial or social transaction. The fabrication process itself could happen domestically, in individual homes—if 3D printers become as ubiquitous as inkjet printers—or in neighborhood-level fabrication facilities.

Fab Lab by Applied Nomadology

Education, traditionally, is a one-way flow of information from teacher to student. Yet tools for building and making invite anyone to create knowledge through personal experience and to diffuse that knowledge through networks of peers. Fab Labs put tools for building and making into people’s hands, inspiring creativity and community. A global network of these spaces, like this one in Amsterdam, provides citizens with unprecedented access to tools, inviting them to create anything and everything they can dream of. Fab Labs harness the power of networks—open sourcing, digital design, and social media—and enable the compelling experience of fabrication, as people see their ideas become reality and create something tangible and useful. The new pedagogical model is based on the idea that people learn much more effectively if they engage with something personally meaningful rather than passively absorb ideas.

Building a worldwide network of local communities around neighborhood fabrication facilities is the vision of Fab Lab, a program that began at MIT. Since the doors of the first Fab Lab were opened in 2001, new shops have cropped up around the world, from campuses to inner cities to rural villages, offering tools for digital and physical fabrication. The projects coming out of them have a local inflection, as communities come together to solve problems and generate new ideas—at a Fab Lab in Norway, for example, shepherds put together radio-frequency ID tags for tracking wandering sheep. The founder of Fab Lab, Neil Gershenfeld, explained the idea and genesis of the project in a TED presentation. “Instead of talking about it, I’d give people the tools. This wasn’t meant to be provocative or important, but we put together these ‘Fab Labs.’ And they exploded around the globe . . . The real opportunity is to harness the inventive power of the world, to locally design and produce solutions to local problems.”[9] This is a new form empowerment—Fab Labs allow people to modify or “hack” the world around them, rather than passively absorbing information and products. As people design and construct technology themselves, it becomes localized, instrumental, and practical.

Fab Labs are places not only for production but also for learning. Crucially, each lab is the nucleus of a fabrication-focused community. Many labs host weekly classes, workshops, and social events. “The message coming from the Fab Labs is that the other 5 billion people on the planet aren’t just technical sinks, they’re sources,” and they are propelled by a new possibility of merging education, experimentation, and making.[10]

The first two industrial revolutions reshaped cities, and today’s decentralized fabrication might have no less profound implications for urban form. Production could be realigned with daily life as manufacturing exits the factory. Society could return to a preindustrial model, one that is local and user-centric—and futurecraft can be applied to guide the changes. New domestic typologies for the twenty-first century might recall medieval cottages in Great Britain, Peranakan shop houses in Singapore, or *machiya* in Kyoto’s artisan districts, combining dwellings with fabrication.[11] If not in individual homes, a dispersed urban platform for community fabrication activity may be spread throughout the city, establishing an open infrastructure that turns community members into makers and becomes the center for sharing knowledge, creating, and socializing.

This vision is the ultimate capitulation of industrial-era zoning. The city fabric would be reconstituted as the workplace and the home collapse into a hybrid unit and as a more social, community-based model blurs formerly distinct urban districts. The city may come to life in new ways. “One potential outcome of all this, where zoning and other policies allow it, is a clustering of the new-style live/work dwelling in twenty-four-hour neighborhoods that effectively combine local attractions with global connections. These—not isolated, independent electronic cottages—will be the really interesting units in the twenty-first-century urban fabric.”[12] Not only will design and production respond to local conditions in a sustainable and targeted way but the city will become more livable. Spaces of human habitation will become functionally intermixed to the point of being broadly homogeneous yet vibrantly active. When the factory is everywhere, cities will be productive on a fine-grained (human) scale.