INTEGRATED NEIGHBOURHOOD SYSTEMS

INTEGRATED GUIDELINES FOR SUSTAINABLE NEIGHBOURHOOD DESIGN

Urban Morphology & Complex Systems Institute 2021

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INTEGRATED NEIGHBOURHOOD SYSTEMS

INTRODUCTION

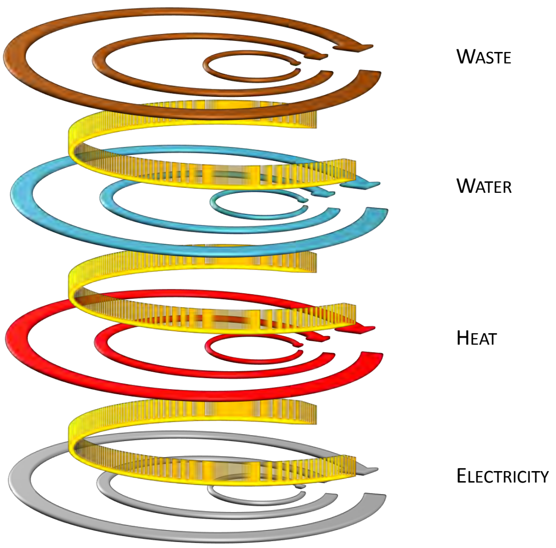
SYSTEM INTEGRATION IS ESSENTIAL

Approximately 70% of the infrastructure required in 2050 is yet to be built. An integrated and circular approach holds the potential to both preserve and increase the well-being of a growing urban population and tackle sustainable consumption and production issues.

Looking at cities, we can see that the predominant urban development model is outdated and that often, essential urban functions are managed in isolation of each other. This model is failing and currently three quarters of resource use and greenhouse gas emissions come from cities. According to the International Resource Panel Report, *Weight of Cities*, optimizing systems and creating cross-sector synergies between buildings, mobility, energy and urban design can reduce greenhouse gas emissions and resource use by up to 55%[1]. This would achieve an urban domestic material consumption[2] (DMC) by inhabitant of about 6 to 8 tons per year from the projected 2050 baseline range of 8–17 tonnes per capita per year.[3]

STRENGTHENING INFRASTRUCTURE SYNERGIES AT NEIGHBOURHOOD LEVEL

MULTI-SCALE SYNERGY DIAGRAM: SECTORIAL MULTISCALE LOOPS AND INTERSECTORIAL LOOPS



[1] High penetration of resource-efficient infrastructure technologies (for example, bus rapid transit instead of passenger cars, green commercial buildings instead of conventional office blocks, and district energy instead of boilers and air conditioners) can reduce water, energy, land and metals impacts by 24 to 47 % by 2050 compared to a baseline for these sectors.

[2] Domestic material consumption, abbreviated as DMC, measures the total amount of materials directly used by an economy and is defined as the annual quantity of raw materials extracted from the domestic territory, plus all physical imports minus all physical exports.

[3] IRP 2018.

Integration requires strengthening the synergies and interconnections between neighbourhood subsystems to add value to the whole. Resource efficiency gains can be achieved by leveraging connections and interactions across one or more of the following infrastructure sectors.

- Travel behaviour and transport
- The building and construction sector
- The energy supply sector
- The heat supply, integrating the reuse of waste heat from industrial resources
- Water and wastewater treatment
- Waste Management

Neighbourhoods allow implementing most of these interconnections. Creating synergies between infrastructure requires to situate them so that proximity enables interaction and linkages. Distributed infrastructure (i.e. localized, smaller-scale energy, water, food systems, etc.) deliver multiple linked benefits. For instance, solar panels positioned on public structures can provide shade to urban farming. The water-holding capacity of urban farms can result in a reduction in the urban heat island (UHI) effect.

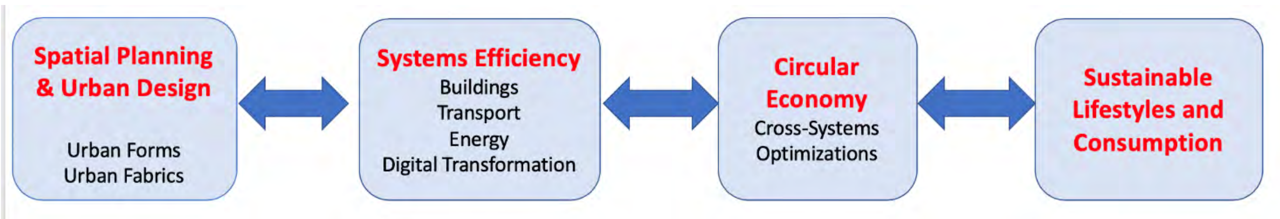
AN INTEGRATED APPROACH DELIVERS MULTIPLE BENEFITS

An integrated approach can leverage opportunities to maximize benefits and synergies, guide the management of trade-offs and inform action prioritization. For instance, driving down energy consumption at neighbourhood level allows meeting diminished loads through local, renewable supplies. Vehicle electrification can reduce transport emissions and support energy storage. Land use and infrastructure development with a diverse mix of uses clustered around public transport stations can minimize travel distances and influence mode share.

Four key policy levers have a multiplicative effect:

- **Spatial Planning and Urban Design.**
- **Systems Efficiency.**
- **Circular Economy.**
- **Sustainable Lifestyles and Consumption.**

These levers initiate of a cascading efficiency chain. Bundling policies addressing all levers and integrating planning across scales and sectors has the potential to reduce by more than 90% CO_2 emissions while delivering sustainable and inclusive urban growth[4]. These four levers are summarized in the chart below.



- ***Urban design influences energy efficiency of buildings and urban blocks.*** Climate responsive shaping and massing enhance natural lighting and cooling. It also determines the amount and distribution of green space. It mitigates heat island effects, and decreases energy demands from buildings. Evidence indicates that higher density and human-scale mixed communities, with urban bioclimatic fabrics, can reduce energy consumption and greenhouse gas (GHG) emissions[5] by about 60%[6].

[4] IRP 2018

[5] For transportation, space heating and cooling, and embodied in the materials used for construction of the built environment.

[6] Salat 2009, Salat et al. 2017, LSE Cities and EIFER 2014, Salat 2018.

- ***Then, building design (shape and bioclimatic features) and energy efficiency (envelope and heating & cooling systems) can further lower this demand by 60%.***

- ***With a strongly minimized energy demand, a higher share of renewables and waste to energy processes can supply the remaining demand, eventually leading to net zero-carbon neighbourhoods.***

- ***Behavioural changes and sustainable consumption and lifestyles are also critical all along this efficiency chain*** and evidence suggests that they could reduce energy demand by a factor of at least two[7].

The integrated systems approach comprises four key strategies.

OPTIMIZE WITH SMART SYSTEMS
INTEGRATE SEAMLESS MOBILITY AND PLANNING
DECARBONIZE NEIGHBOURHOOD ENERGY
REDUCE RESOURCE USE WITH CIRCULAR MATERIAL CHAINS

[7] Salat 2009.

CASE STUDY: INTEGRATED NEIGHBOURHOOD SYSTEMS, THE EXAMPLE OF Bo01 DISTRICT, MALMÖ, SWEDEN[8]

The Bo01 high-density mixed-use development in Malmö, Sweden, is based on innovative planning procedures. The sustainability accomplishments of Bo01 are attributable in part to the control the city exerted through ownership, goal formulation, and planning. A very broad definition of sustainability required new integrated approaches in collaboration by the city, developers, planners, and designers. The outcomes of the project included outstanding aesthetics in the plan and the individual elements, as well as spaces that foster social interactions at the neighbourhood, and block scales. The density of 122 people per ha is interwoven with 50% open space. Comprehensive planning for energy, water, and waste systems resulted in significant improvements, especially in energy production (which comes entirely from renewable sources) and solid waste management.

[8] This box draws on Fraker 2013 and on Austin 2013.

Urban Planning

The City of Malmö and the SVEBO[9] exposition architects formulated a concept plan founded on a creative evolution of the traditional European perimeter block. The city hired Klas Tham, a well-known architect and planner, to establish the basis for Bo01 and serve as its design director. Tham holistic approach was transmitted to the city officials, departments, and developers through a 'Creative Dialogue'. Through a series of meetings and presentations, the participants developed the 'Quality Programme', which established performance requirements. The dialogue fostered an atmosphere of collaboration and innovation. The 20 developers selected for the project committed to material, technological, environmental, and architectural quality measures before any parcel was sold.

Soil decontamination

The City of Malmö prepared plans for remediating the former industrial site. Measures taken to replace and sequester toxic soils on the brownfield site were coupled with the concept for the stormwater system.

Integrated energy systems

Bo01 generates 100% of its energy from renewable sources including a wind turbine, solar tube and flat panel collectors, and geothermal (heat pump), besides the waste-to-energy conversion systems. The 3MW wind energy plant is in the northern part of the Western Harbour. Photovoltaic cells generate on-site additional electricity for use in the dwellings and to power the heat pumps, fans, and water pumps.

The Tegelborgen building by architect Månsson Dahlbäck features evacuated-tube solar collectors. Photos: ©Françoise Labbé.

An efficient district heating system – augmented by solar collectors – uses geothermal technology. Heat pumps connected to an aquifer contribute heat in the winter and cooling in the summer. To provide heat in the winter, warm summer seawater (21° C) is stored in a limestone aquifer. Conversely, cool winter seawater (16° C) is stored in an aquifer for use in district cooling during the summer. The district heating system is reinforced by 1,200 m^2 of flat panel solar collectors and 200 m^2 of evacuated-tube collectors. These two types of solar collectors on ten buildings generate 15% of the energy used to heat the buildings[10].

[9] Svenska Bostäder, an organisation formed by BOVERKET, the Swedish National Board of Housing, Building and Planning.
[10] Austin 2013.

Eco-Cycle And Waste Management

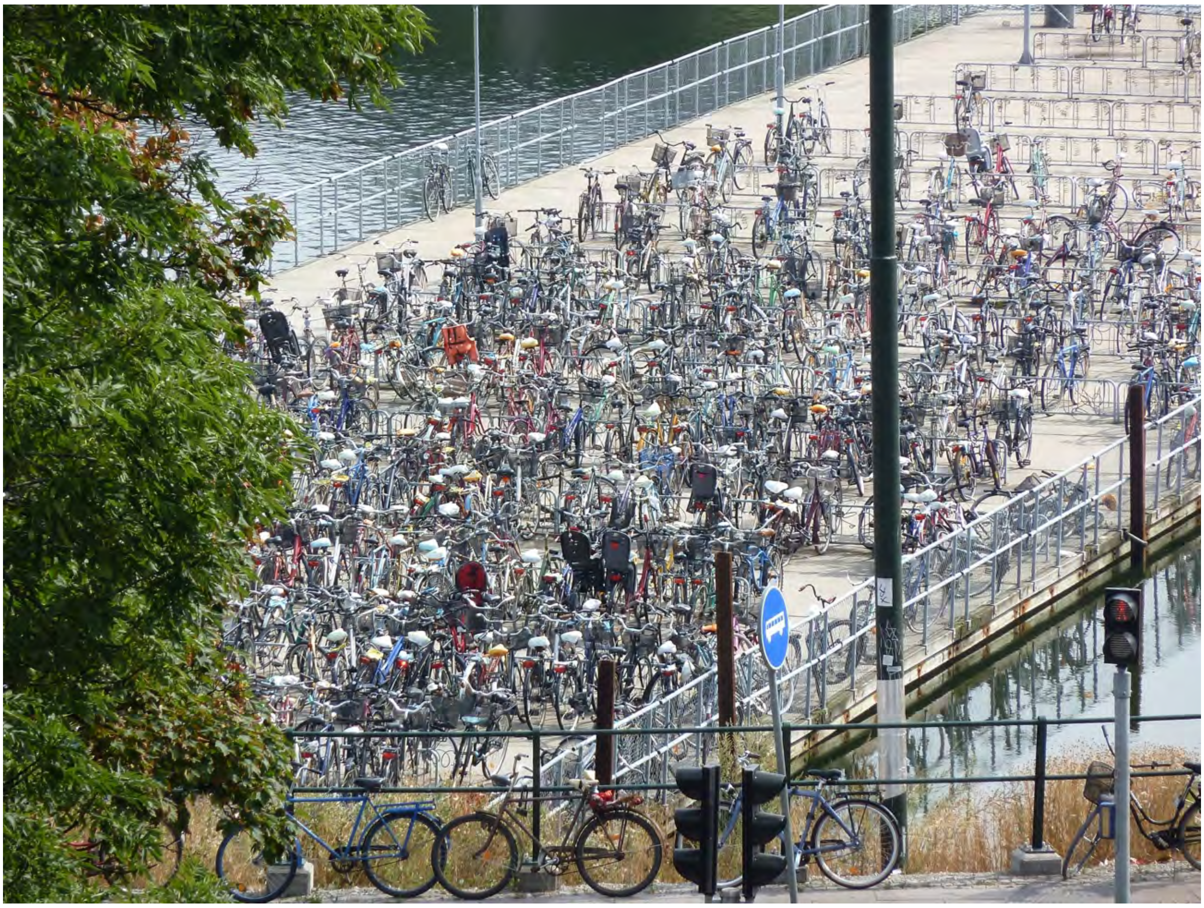
The City of Malmö after extensive analysis of alternative waste and sewage systems, devised a plan to minimize material consumption, reuse materials, and recover energy from waste and residual products wherever possible.

Waste collection in Malmö. Photo: ©Françoise Labbé.

Organic kitchen waste is ground at the residence and collected in underground vaults, from which it is pumped to an anaerobic digestion chamber. The biological treatment of this slurry by bacteria creates biogas (methane), which is drawn off and used to power public buses or used to generate heat and electricity. Similarly, the non-organic waste is deposited in one of three vacuum tubes located in the residential courtyards or within the buildings. The waste is delivered to a central facility where it is either recycled or incinerated to contribute to the district heating system[11].

Mobility

[11] Austin 2013.



Cycling in Malmö. Photo: ©Françoise Labbé.

The City of Malmö prepared a holistic concept first to reduce the need for transport then to support the most environmentally favourable modes, including walking and biking; to make buses accessible at less than 300 metres from each inhabitant with a high frequency (every 6 to 7 minutes)[12]; and finally, to establish provision for 'green' vehicles and carpooling options, all enabled by a mobility management information system. The area is car free. It is well served by pathways dedicated to pedestrian and bicycle use. A little more than eight kilometres of bicycle routes extends from Bo01 through the Western Harbour.

Green Spaces And Stormwater Management

The City of Malmö and SVEBO architects prepared a plan to create a habitat-rich neighbourhood. A minimum Green Plot Ratio[13] ensures greening the ground, roofs, façades, planting beds, permeable paving, and designated habitat areas.

[12] City of Malmö 2006.
[13] Measuring the quantity of landscaped surfaces compared to a development's site area.

This fresh water marsh within a mixed-use courtyard is an effective stormwater treatment system. The vegetation and presence of water create a contrast with the large paved areas near the Öresund. Photo: ©Françoise Labbé.

Green and water in Malmö. The infrastructure is revealed rather than concealed from the residents. The granite blocks and edging avoid accidents by heightening visibility. Photo: ©Françoise Labbé.

The surface stormwater system provides a model of effective design, due in part to high permeability requirements. It secures water retention and is a key amenity for residents. Green roofs, water detention in courtyard ponds, and infiltration through gravel and other pervious paving initiates the stormwater system.

The surface stormwater drainage system at Bo01 features runnels that are less than 25 wide and 35 cm deep. The grating and bridging give access, security, and detailing. The layering of adjacent paving and drainage materials are analogous to patterns in Japanese Zen gardens, such as Ryoanji. Photo: ©Françoise Labbé.

All the stormwater conveyance is on the surface, which demands very accurate grading, novel structures, and excellent construction quality. Water flow is directed through narrow channels to rain gardens and finally to either a saltwater canal or to the Strait. The stormwater system components are revealed as elements of the urban design. Stormwater is directed to small, vegetated basins for infiltration and water quality improvement before discharge. Some of these basins are within the interior courtyards. The networked and distributed nature of these elements creates a finely scaled infrastructure[14].

Buildings And Living

The City of Malmö created an area development plan and rules concerning green space and colour pattern. This framework is flexible enough to provide a rich variety in the design of housing schemes.

Building and living in Malmö. Photo: ©Françoise Labbé.

[14] Austin 2013.

Information And Knowledge Dissemination

Among many actions, public educational projects have ensured that Bo01 has a focus on information and know-how about sustainability.

Lessons Learned

The integration of sustainable systems and urban design is outstanding. The more formal building edges and waterfront promenades shelter the inner urban fabric from the winds. The semi-public courtyards with their angled shapes offer surprise, discovery and enhanced detailing derived from the eco-cycle itself. They establish supportive microclimates, and implement biodiversity measures. The demonstration of a surface-only stormwater management is an important achievement. The designers showed how planning and attention to elaborate detail in system integration can solve functional, aesthetic, and safety concerns and create many neighbourhood features valued by the residents[15].

INTEGRATED SMART CITIES

Source: Optiva Darna, Fadwa Sube.

The 'smart city' concept initially referred to initiatives that use digital and ICT-based innovation to improve the efficiency of urban services and generate new economic opportunities in cities. A smart city approach, as defined by the United Nations, 'makes use of opportunities from digitalization, clean energy and technologies, as well as innovative transport technologies, thus providing options for inhabitants to

[15] Austin 2013

make more environmentally friendly choices and boost sustainable economic growth and enabling cities to improve their service delivery' (United Nations 2016).

Technology is a critical factor in the way cities function. Disruption through technology has brought forth some of the most efficient answers in urban life today. Cities are increasingly adopting integrated smart solutions to manage traffic, safety, energy and resources from the spatial data collected using various sources, including sensors, cameras, GPS, social media sites, and mobile devices.

Smart cities are an integrated concept. By nature, they need to be cross-sectoral and encompass sectors such as energy, transport, health and medical care. The expansion of integrated smart systems is driven by many factors

- an envisioned transition to 100% electricity-powered world.
- falling costs of renewables and smart devices and computing.
- cities' demand for actionable data platforms to monitor systems.
- government investments in emerging technologies to enhance public safety infrastructure.

Sustainable smart city concepts also encompass citizen participation, sustainable development and better governance. A smart city also needs to be a place for engaging the community and for innovative job creation rather than just focusing on solving urban problems.

THE GOVERNANCE OF SMART CITIES AND INCLUSIVE GROWTH

A human-centric approach is key to make a city smarter. This is why the OECD defines smart cities as 'initiatives or approaches that effectively leverage digitalization to boost citizen well-being and deliver more efficient, sustainable and inclusive urban services and environments as part of a collaborative, multi-stakeholder process' (OECD 2018).

Smart cities need smart governance. There is need for an integrated and holistic approach to address urban challenges through digital innovation in a city's governance, planning, and infrastructure investment. Business and contractual models need to adapt to rapidly changing urban environments and encompass a more holistic approach, sometimes re-regulate rather than simply deregulate, and leverage public procurement, including at the pre-procurement stage. The wealth of data that can be collected in cities today -- while an area that has to be carefully regulated – can help solve problems and deliver services much more efficiently if the right policy frameworks and regulations are in place to harness benefits and avoid risks.

Smart cities need multi-stakeholder engagement. Smart city projects can only be successful if they engage a variety of stakeholders, such as technology developers and service providers (who make technology); city developers (who add technology); city administrators (who use technology); residents and local companies (who purchase technology).

Citizens are not only recipients but also actors of smart city policies. Putting people at the centre of smart cities means co-constructing policies with citizens throughout the policy cycle. It is important to ensure stakeholder engagement in local governance and collaborative partnerships to boost civic engagement with citizen participation and feedback, co-creation and co-production models, citizen-centred services and engagement platforms. A smart city is a place whose inhabitants equip themselves with the means to understand their interactions, increase their efficiency and get more for less. It manages supplies frugally to optimize each decision for the common welfare. It creates a space where it is good to live daily and where everyone feels in charge of a better future. Such a city involves behavioural change and can only be a collaborative project. An example is the Smart Cities

Challenge programme in Canada[16]. It is a competition open to local and regional governments and indigenous communities, which aims to empower communities to adopt a smart city approach to improve the lives of their residents through innovation, data and connected technology. This competition was designed to engage all communities, including rural and remote communities that have little to no access to the Internet. To ensure that all communities would be able to participate, the government put in place a series of incentives to help small cities build up capacity and develop their proposals. In total, the government received 130 applications covering a wide range of solutions in areas such as food security, reducing isolation of the senior population, integration of migrants, and accessibility for people with disabilities. One of the main aspects of the competition is that all ideas have to be shared and be applicable to other communities.

Digital technologies can help engage a broader range of stakeholders in the governance of smart cities going beyond the construction phase, such as management, operations and the promotion of innovative industries. Digital technologies are offering new tools to engage citizens and other stakeholders in the definition of the main urban challenges and potential solutions. Citizen and stakeholder engagement can take place on different levels within a continuum of mechanisms through which engagement can take place. Engagement modalities vary from basic communication of information, which represents the weakest form of engagement, to full co-production, co-delivery and co-evaluation, which implies a balanced share of powers among the stakeholders. Smart cities that put citizens at the centre can therefore serve as a vehicle for social change and sustainability. The governance of smart cities requires addressing important social challenges, for example in terms of ensuring digital inclusion in new forms of public participation. Engagement needs to go beyond simply listening to citizens and implies co-constructing public policies with citizens (OECD 2020).

Digitally enabled participation is changing people's expectations about their relationship with governments. There is need for a shift from the government simply anticipating the needs of citizens and businesses towards citizens and businesses determining their own needs and addressing them in partnership with governments. Data can help enable such citizen-driven approaches, for example through open government data and crowdsourced data. Leveraging Open Government Data (OGD) for more inclusive policy making implies adopting community-oriented approaches to engage non-government actors, such as civil society, academia and businesses (OECD 2020).

THE DIGITALIZATION OPPORTUNITIES

The Fourth Industrial Revolution is unfolding at an exponential rather than a linear pace. Major developments including big data, Artificial Intelligence (AI), the Internet of Things (IoT) and new energy forms are transforming systems. The growing potential of big data algorithmic processing is increasingly providing insight that fosters creation of innovative urban services. Real-time energy demand-supply balance or journey optimization allow more efficient use of infrastructure assets while delivering higher quality and convenience. The great leap made in Artificial Intelligence in recent years is a revolution, as it has enabled the emergence of autonomous vehicles.

Internet of Things technologies are also significantly influencing our future as they introduce a continuous communication channel between energy and mobility stakeholders, skyrocketing the ability to capture and share data. Fifty billion devices are expected to be connected in the years to come with cheaper data transmission. Soaring urban data volumes become available thanks to lower sensors and data storage costs and due to the generalization of digital communications and transactions. Advanced analytics, such as machine learning, is progressing quickly. Digital technologies have improved energy systems for decades and the pace of adoption is accelerating.

[16] https://www.infrastructure.gc.ca/cities-villes/index-eng.html

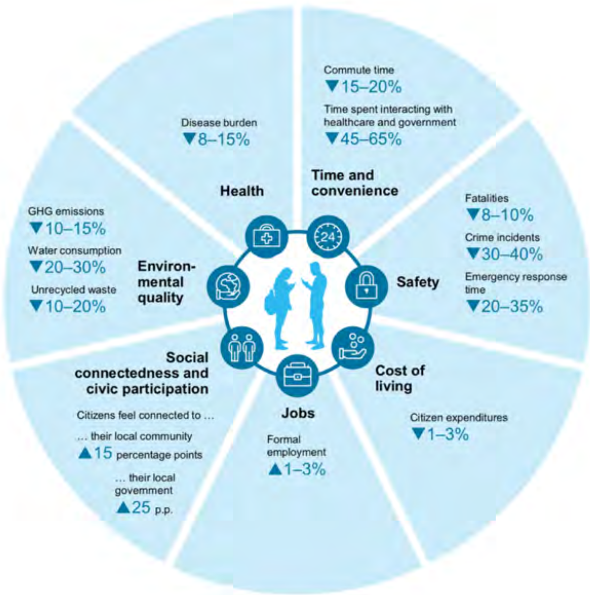
Global investments in digital power infrastructure and software have added by 20% per year in recent years[17].

Finding patterns and insights in data with deep learning[18] helps municipal governments to allocate resources wisely, respond to fluid situations, and plan for the future. Real-time data allows agencies to monitor events as they unfold, perceive how demand flows are evolving, and respond with faster and less expensive solutions. Smart technologies are changing the nature and economy of infrastructure. They reduce the cost of collecting information on usage patterns – and with an unprecedented volume of data points on hand, municipal governments, employers and residents can find new ways to optimize systems. For instance, the digital shift in energy will break down boundaries between energy sectors, increasing flexibility and enabling integration across entire systems[19]. As the digital transformation will progress, a highly interconnected system will emerge, blurring the distinction between traditional providers and consumers, offering more and more opportunities for renewable energy deployment, with more local energy trading and network services.

'Smartness' uses technology and data to make better decisions and to enhance quality of life, from the air residents breathe to how safe they feel on the streets. McKinsey Global Institute[20] found that cities could improve some key quality of life indicators by 10–30% – numbers that translate into saved lives, decreased crime, shorter commutes, a lower health burden and avoided carbon emissions. Smart technologies can help cities make significant progress toward 70% of the Sustainable Development Goals[21]. Digital tools could reduce fatalities by 8–10 %, accelerate emergency response times by 20–35%, shave the average commute by 15–20 %, lower the disease burden by 8–15 %, and cut greenhouse gas emissions by 10–15 %[22].

Smart technologies are a powerful tool to optimize the infrastructure, resources and spaces they share. ICTs support business functions, city logistics and grids, transport, delivery of basic services, environmental management systems, government operations, data-driven industries like finance, and people-to-people interactions. Deployment of smarter networks ('Smart'/'e'-approaches) to manage neighbourhood systems can increase the quality and effective delivery of services, empower citizens, address environmental challenges and disaster risks. Examples are smart grids, smart transport, smart energy, e-participation, e-services, e-government, etc. Digital technologies are already widely employed in the end-use sectors of energy, with potentially the large-scale deployment of disruptive technologies such as autonomous cars and smart home systems. Urban shared mobility programmes enabled by digital transformation improve air quality and social inclusion, and reduce congestion. The potential is huge. In Lisbon, for example, studies have shown that a fleet of shared taxis could maintain resident mobility levels using only 3% of the current vehicles[23]. The global adoption of automated shared electric vehicles could diminish global vehicle inventories by one third[24].

[17] IEA 2017.
[18] Deep learning (also known as deep structured learning or hierarchical learning) is part of a broader family of machine learning methods based on artificial neural networks.
[19] IEA 2017.
[20] McKinsey Global Institute 2018
[21] McKinsey Global Institute 2018.
[22] McKinsey Global Institute 2018.
[23] Bai et al. 2018.
[24] Bai et al. 2018.



Smart city applications can improve some key quality-of-life indicators by 10 to 30%. Source: MGI 2018.

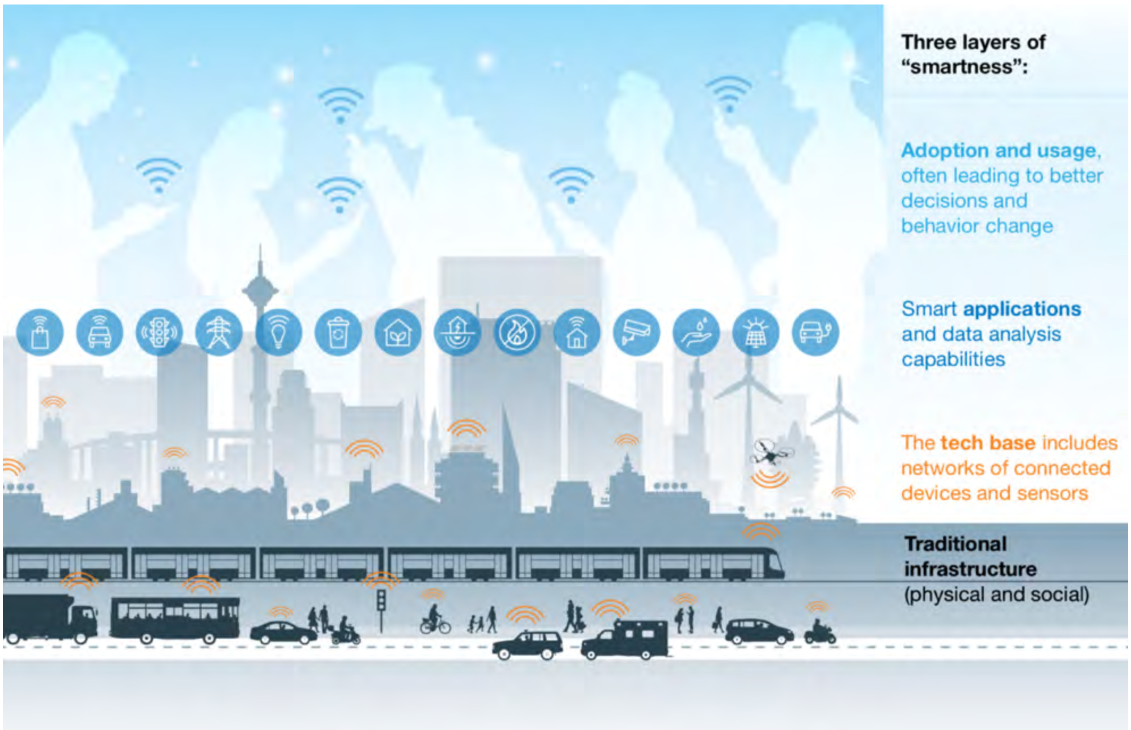
Putting information in real time in the hands of people and businesses allows them to make better decisions and play a more active role in shaping the city performance, making it possible to do more with less. Connected apps and smart tools can save lives, prevent crime and decrease the burden of disease. They can save time, reduce waste and even help strengthen social connectivity. When cities operate more efficiently, they also become more productive places to do business. Intelligent solutions react to demand. They encourage people to utilize public transport during off-peak hours, to change routes, use less energy and water at different moments of the day, and reduce stress on the health system through self-preventive care. Smart systems respond more dynamically to the requirements of residents. Smart cities need to focus on upgrading results for residents and getting their active participation to shape the places where they live.

Smart city solutions contribute to the effective management of urban places, improving connectivity, sustainability, and liveability. Across all areas of city life, technology and data are used to analyse and optimize, enhancing outcomes and improving quality of life. The sections below outline examples of smart city sustainable applications.

Three layers work together to make a smart city.

The first is the technology base, which includes a critical mass of smartphones and other sensors connected by high-speed communication networks, and open data portals. The sensors read variables such as traffic flow, energy consumption, air quality and many other aspects of daily life and make the information accessible to those who need it. The second layer consists of applications. Translating raw data into alerts, information and actions requires the right instruments, and that's where technology providers and application developers come in. The tools are now available in several areas: security, mobility, health, energy, water, waste, economic growth and housing, engagement and community. The third layer is for public use. Many applications only succeed if they are widely adopted and manage to change behaviour. Many of them give citizens more transparent information that they can use to make better choices[25].

[25] McKinsey Global Institute 2018.



Smart cities add digital intelligence to the urban world to solve public problems and achieve a better life. Source: MGI 2018.

Smart Traffic Systems

The rising demand for road safety of travellers and surging call to cut traffic are propelling IOT based integrated traffic systems. For instance, sensors in vehicles can be used to save maintenance costs by predicting when it is needed. They can also be linked to broader systems that help to manage congestion across the city. Integrated traffic systems that are gaining traction are sensors (infrared, weigh-in motion, and acoustic), monitoring (traffic control, traffic monitoring, and information provision), and hardware (sensors, display boards, radars, surveillance cameras, interface boards, smart traffic lights, and others).

Smart Energy

Cities around the world are grappling with the challenge of reaching Net-Zero goals. City and neighbourhood-level action can provide the biggest carbon-mitigation return on investment and accelerate inclusive clean energy transitions. Digitally enabled energy systems can be a key tool, leveraging the latest innovations to enable more distributed, integrated and multi-directional urban energy systems, which can reduce energy demand, improve grid stability, create household energy savings and more. Smart energy comprises devices that have inbuilt Artificial Intelligence to carry out their daily activities without any human interference. For instance, a solar-panelled building produces some of the energy it uses. An IoT-enabled solution collects and analyses data about weather, energy intake, and energy market prices. The system then determines the most cost-effective way to use generated energy. Options include consuming it immediately, storing it, or selling it at a high market price. Smart energy features multiple technologies such as smart grids, smart homes, and smart solar and digital oil fields. Smart grids use digital communication technologies in electricity generation, transmission, and distribution, thereby automating the value chain. They consist of a two-way communication between the utility and its customers. They comprise sensing along the transmission lines. The smart grid technology functions much like the Internet, where electricity can be managed with controls, computers, automation, and new technologies and equipment working together, to enable the electricity to be handled digitally. Smart grids incorporate devices and technologies such as smart metres, grid optimization, distributed generation, and storage.

Smart Homes

Smart homes offer data driven technologies. For instance, lighting and heating can be controlled remotely by smartphones. Many IoT devices and applications are emerging for use in the home, including connected thermostats, smart appliances, and self-guided vacuum cleaners. As these devices evolve, the greatest economic impact from the Internet of Things in the home will be in chore automation, which can cut 100 hours of labour per year for the typical household.

Smart Offices

The introduction of IoT in smart office applications has paved the way for new concepts and technologies. Earlier, the functions of offices such as heating, ventilation and air conditioning (HVAC); security; lighting were operated separately. The Internet of Things (IoT) makes possible for a range of devices and sensors to communicate wirelessly over the Internet, without the need for direct human interference. Key benefits are in office security and energy management.

Health and Fit Tech Applications

The Internet of Things has a great potential for transformative change in human health. Connected devices can continuously monitor patients – particularly those with chronic conditions such as diabetes. IoT can strengthen patient adherence to prescribed therapies, avoid hospitalizations, and improve the quality of life for hundreds of millions of them.

Air Quality

IoT-enabled smart cities use sensors to collect data about weather and air quality. When air quality is deemed poor, the city takes immediate action (such as offering free public transportation) and can easily assess the impact of corrective measures.

Waste Reduction

Real-time information about resource consumption, be it electricity moving through a smart grid, gas flowing through pipes or material required in a factory, makes it possible to apply resources as needed as well as identify leaks. This reduces or eliminates waste.

Interoperability is key for reaping the benefits of system integration

By blending physical and digital realms, the Internet of Things (IoT) vastly expands the reach of information technology. The myriad possibilities that arise from the ability to monitor and control things in the physical world electronically have inspired a surge of innovation. To obtain the greatest benefits of IoT implementations, which require creating highly complex systems and integrating technology, investment, and talent across both space and time, interoperability is key. This interoperability between IoT systems is critical to capturing maximum value. On average, interoperability is required for 40% of potential value across IoT applications. Making IoT applications interoperable – linking a patient's home health monitor to the hospital's health informatics system, for instance – is a complex system design challenge that demands coordination on many levels (technology, capital investment cycles, organizational change, and so forth). Moreover, most IoT data are not exploited currently. For example, only 1% of data from an oil rig with 30,000 sensors is examined. The data that are used today are mostly for anomaly detection and control, not optimization and prediction, which provide the greatest value.

Smart planning should be combined with asset development to get the most out of smart systems

Smart city technologies help cities get the most out of their assets, whether they have large legacy systems or build new infrastructure. Smart technologies can add state-of-the-art capabilities as the main components are upgraded. Investing in infrastructure once trapped cities in very long-term, capital-intensive plans, based on a static snapshot of how they expected activity to evolve. Now, using the right combination of traditional construction and intelligent solutions, they can react more dynamically to changing requirements. Governments can make more flexible, data-driven investments with shorter planning cycles. If population growth is increasing in a remote area, adding a new metro or bus line with the accompanying fleet expansion can take years. On the other hand, an on-demand minibus service operated by the private sector could be functional much more quickly. Smart city applications become more effective when combined with low-tech and complementary policy measures.

CASE STUDY: SMART AND INCLUSIVE CURITIBA, BRAZIL[26]

The city of Curitiba was selected as the most connected and intelligent city in Brazil. Curitiba is the capital of the state of Parana, with a strategic location in Mercosur, close to São Paulo and the Port of Paranagua (the second largest in Brazil). In 1974, Curitiba developed the first Bus Rapid Transport (BRT) system, a system of bus corridors that revolutionized the way citizens moved across the city. The city also provided its residents with free access to Internet in public spaces. Curitiba is developing projects such as Fab Labs, urban farms, apps to help citizens navigate the city and innovation hubs including the Vale do Pinhao (Pinhao Valley) or Bom negócio (Good Business). Curitiba is promoting a 'smart city movement' to build an innovation ecosystem to promote smart solutions that are aligned with the implementation of the SDGs. An example of this effort is the restoration of an entire community in a location named Caximba, which may become the largest socio-environmental project in the city to recover an area with 30,000 people living under difficult circumstances. Another project involves the launch of the first public co-working space in Brazil, freely accessible to all citizens and with 430 solar panels installed at the City Hall. The city uses 70 indicators divided into 11 axes (mobility, environment, energy, technology, innovation, economy, education, health, safety and governance) to ensure that technology benefits all citizens and that the impact of its policies can be measured.

CASE STUDY: TWO PILOT PROJECTS: SEJONG AND BUSAN IN KOREA

The National Pilot Smart City was implemented in Korea to demonstrate and integrate technologies related to the Fourth Industrial Revolution to sites without development plans. In addition, it is pursuing the goal of presenting the future smart city leading model by creating an innovative industrial ecosystem that can implement creative business models. National pilot smart cities are Sejong and Busan. In 2018, two cities – Sejong City and Busan Metropolitan City – won Korea national call for smart city pilot projects. The purpose of these pilot projects is not only to solve urban problems, but also to provide smart city testbeds for cutting-edge smart city solutions and establish innovative industry ecosystems for smart cities. These pilot projects are large-scale development projects from scratch, located in greenfields districts. The pilot project in Sejong is located in the 5-1 residential district. It covers 2.7 km^2 and a

[26] Source: Presentation of Curitiba (Brazil) during the 1st OECD Roundtable on Smart Cities and Inclusive Growth (OECD 2020)

population of 19,000 residents in 8,900 households. The pilot project in Busan is the Eco-Delta City District. It covers 2.8 km^2 and a population of 8,500 residents in 3,300 households.

The two pilot smart cities focus on different themes

- Sejong focuses on smart mobility and health care. First, the master plan of Sejong smart city gives priority to transport based on innovative technologies such as driverless vehicles and cars powered by hydrogen and electricity. Car-sharing is an important part of Sejong's goal to reduce the number of cars used per capita by two thirds by 2040. Sejong also plans on reducing traffic jams by using AI embedded in a traffic management system. Second, Sejong will use wearable devices and robotics in homes, public spaces and medical facilities to improve the responsiveness and delivery of health care. For example, Sejong plans to use AI in homes to detect medical emergencies such as falls, injuries and illness. Drones will collect images and video information to provide relevant information to medical professionals in hospitals.
- Busan put emphasis on smart water management and robots. Smart water management includes smart water meters, automated detection and drainage of pollutants, and a water re-use system. The master plan of Busan smart city calls for robots to help parking and returning cars like an automated valet service. Robots can also assist in detecting parking violations.

After announcing their basic concepts in 2018, Sejong and Busan are developing their space planning and smart city solutions. In 2021, residents will move into the smart city districts where they will have access to cutting-edge smart city infrastructure such as data centres, IoT, self-driving cars and drones. In addition, national R&D projects are being carried out. For example, smart grid R&D projects and smart water management R&D projects are being tested in the two pilot projects. The designated districts in Sejong and Busan will also be able to benefit from exemptions from previously restrictive regulations (e.g. through more relaxed location requirements).

CASE STUDY: INTEGRATED INNOVATION IN FRENCH DREAM TOWN SMART CITY IN HANGZHOU

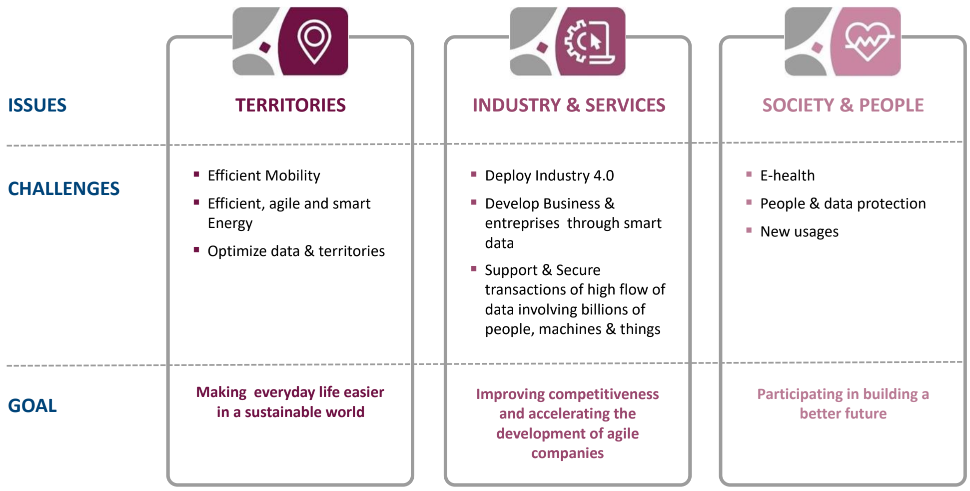
French Dream Town in Hangzhou is rethinking how to 'live smart' in a digital era. It is an experimental smart city that provides living labs as an essential tool to facilitate urban innovation. It innovates through an experimental and citizen-centric approach. Its goal is to achieve holistic sustainability. It is designed as an integrated urban area with improved navigability, tighter-knit community, better public realm, and that is less resource intensive. It combines the urban landscape and nature, digital technology, human sciences and art.

French Dream Town in Hangzhou. Design: Anouk Legendre, XTU (Southern Part); Serge Salat (Northern Part). Source: Optiva Darna, Fadwa Sube, in collaboration with Systematic, Paris Region Deep Tech Cluster. Image: Nanfang Institute.

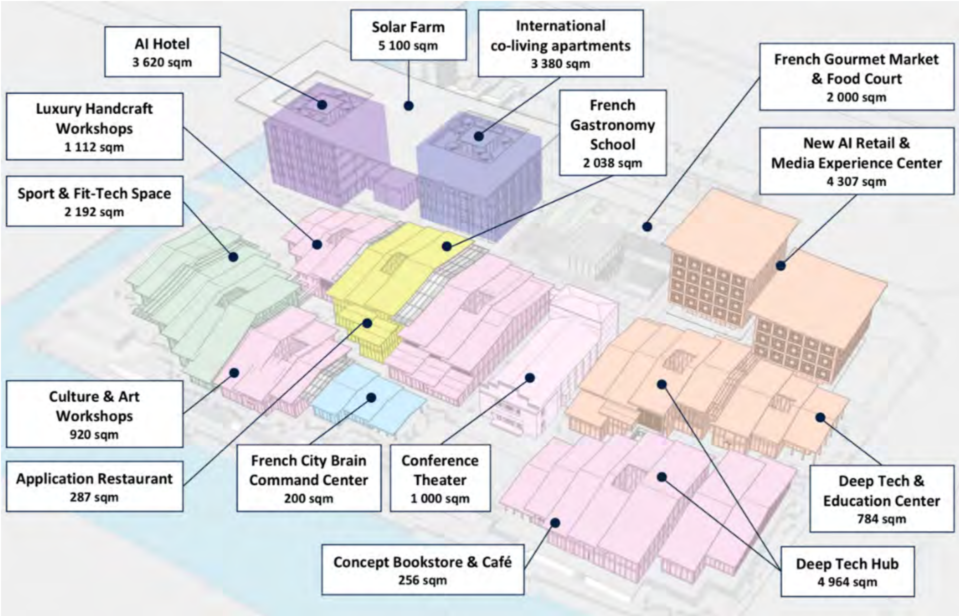
French Dream Town in Hangzhou. Design: Anouk Legendre, XTU (Southern Part); Serge Salat (Northern Part). Source: Optiva Darna. Image: Nanfang Institute.

French Dream Town, developed by Optiva Darna and Systematic, the digital cluster of Ile de France Region, weaves together three key transformative layers: unique identity in design; innovation in cutting-edge digital systems; openness in its dynamic growth paradigm fostering a new economy, creativity, and value creation model. The project blends harmoniously

- Ecological values and people centric design.
- Ground breaking deep tech innovation.
- Futuristic AI experiences fusing two fascinating cultures.
- Sustainable high-tech living with a collaborative mix of retail and technology.



An integrated smart city approach. Source: Optiva Darna, Fadwa Sube.



French Dream Town in Hangzhou, Smart City programme. Source: Optiva Darna, Fadwa Sube.

French Dream Town in Hangzhou. Design: Anouk Legendre, XTU (Southern Part); Serge Salat (Northern Part). Image: Nanfang Institute.

Smart Carbon Neutral Design With Unique Identity

French Dream Town first layer of smartness is place making through innovative architecture harmonizing Chinese culture and green design. Combining ancient street life of Southern China and contemporary spaces creates a unique place: a graceful and peaceful urban landscape by the water. A mesh of small green spaces is blended with the smooth horizontal rhythm of abstracted Southern Song Dynasty roofs. Windows with elegant and restrained lattice work are both minimal modern and reminiscent of traditional Chinese Southern Song Dynasty craftsmanship. The design provides a distinctive experience and reduces energy and resource impacts by its sound bioclimatic approach and unique water tech. French Dream Town comprises all the elements that work together to create a people-centric place: planning, architecture, materiality, green space, amenities, infrastructure, art and cultural connections. It offers a lifestyle enhanced by AI, deep tech, and IoT. It unfolds experiences in food, fitness, healthcare, education, entertainment, culture. The aim of the Green Strategy is to make the Northern Part[27] positive energy and carbon neutral. The design develops effective architectural forms and proposes technically viable measures.

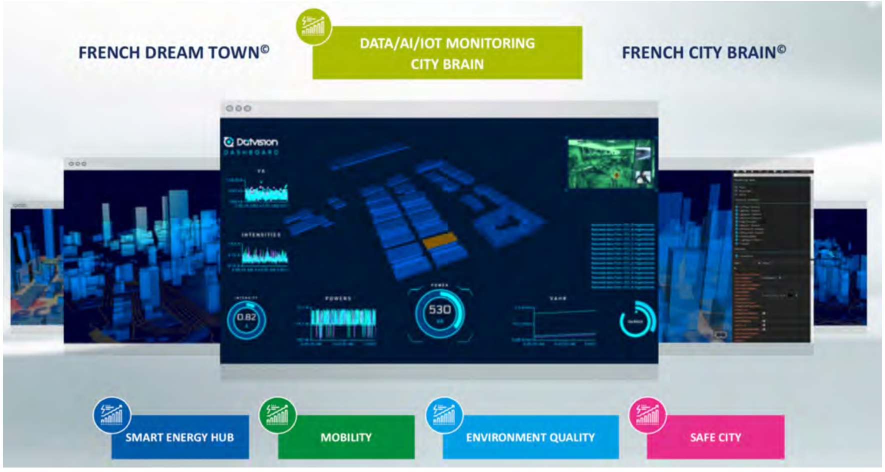
French Dream Town in Hangzhou. Design: Serge Salat (Northern Part). Image: Nanfang Institute.

The buildings will be demonstrators of sustainable technologies: solar energy and optimization by Artificial Intelligence, intelligent landscape design, 3D digital printing. Vertical greening will shade buildings. These plants will be fed by rainwater or grey water from the buildings, they will clean up the water, and shade and cool the buildings. Solar panels and energy optimization, green facades, filtering gardens, digital construction, wooden pavilion with modular architecture, the technologies will be integrated in different parts of the project. This 'passive' building innovation will spend less energy, using shade from roofs and patios to naturally cool buildings. With its bioclimatic design, its entirely renewable energy and its digital information networks interwoven with physical urban space, the highly efficient, adaptive, and resilient Dream Town smart city will be carbon neutral.

Smart Deep Tech Platform For Efficient City Management

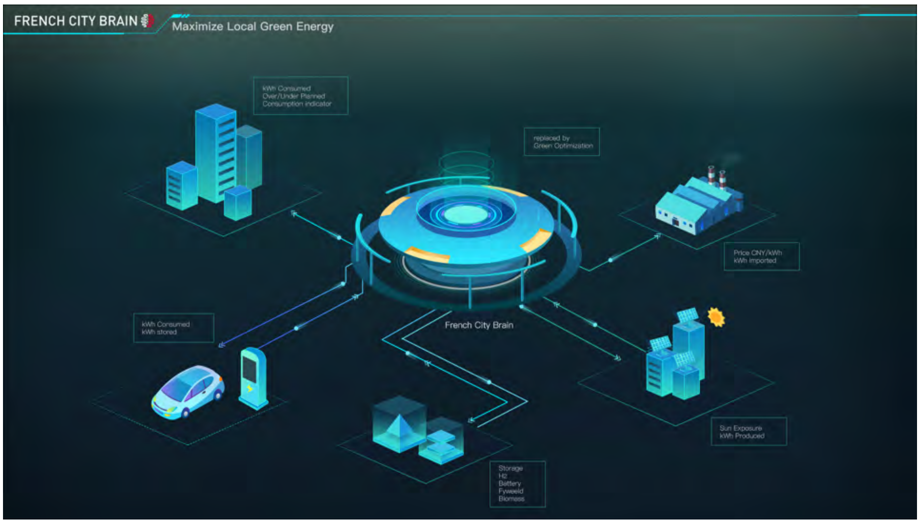
French Dream Town focus on connecting and integrating information systems that used to operate independently from each other. A smart city control centre and platform is therefore built to reap synergies among existing data and services. French Dream Town advanced infrastructure combines ICT with infrastructure in transport, safety, and built environment. It aims at realizing the full potential of IoT for managing city systems. It utilizes a vast array of sensors and actuators. They are connected by networks to computing systems. This allows to monitor building energy, the consumer enhanced experience, the connected objects and machines in industrial production processes. It will comprise networks of connected devices and sensors, smart applications and data analysis capability, with cloud Artificial Intelligence, IoT/AI/embedded machine learning, green blockchain, smart energy storage, WI mesh networks. With its City Brain, French Dream Town successfully addresses a set of system issues that are critical for interoperability. It captures the extensive benefits of interoperability across a multiplicity of settings such as homes, offices, factories, worksites, retail environments, cities, vehicles, and the outdoors.

[27] Comprising a hotel (3,376 m^2), an apartment building (3,106 m^2), and an AI experience building (6,163 m^2) for a total comprising 12,655 m^2).



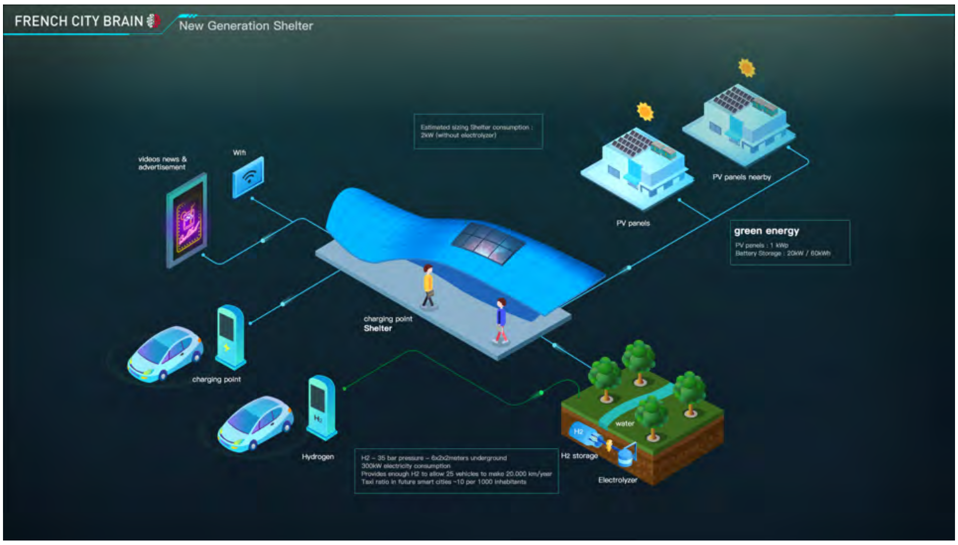
French City Brain is an integrated and collaborative IOT/Cloud platform. It delivers optimized sustainable living solutions: Edge-IOT/cloud infrastructure, smart energy hub (Bio-waste management/Multi-energy production/Storage solutions), air quality/AI solutions, WI mesh for Safe City and Green Blockchain. Source: Optiva Darna, Fadwa Sube.

French City Brain Use Case 1. Dynamic district energy optimization. French Dream Town has leveraged on its multiple urban data flows integration platform to design innovative solutions in smart energy, smart grid technology, smart solar technology, and Home Energy Management Systems. The district will be equipped with sensors/actuators. They will communicate on a local wireless loop connecting the buildings and production assets to the cloud and the French City Brain. This will create value for the developer – CAPEX – by avoiding grid reinforcement/oversizing costs, reducing infrastructure footprints, and differentiating services. This will also produce value for the facility manager – OPEX – by diminishing network connection fees, guaranteeing local green energy supply, and decreasing commodity costs.

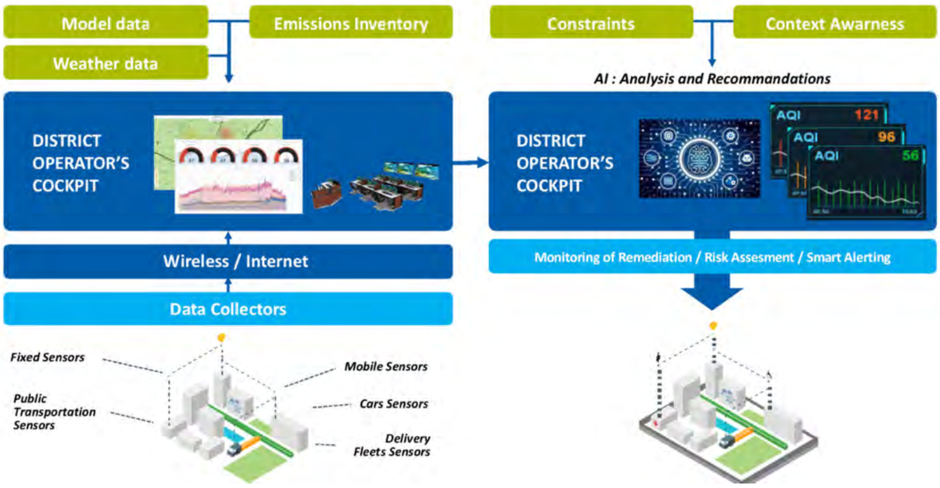


Maximization of local green energy. Source: Optiva Darna, Fadwa Sube.

French City Brain Use Case 2. New generation shelter mobility for electric and hydrogen vehicles. The Shelter is an innovative urban infrastructure dedicated to facilitate both green energy and decarbonized mobility integration in the city. The Shelter is providing various services: a connected experience when people wait at the bus stop; a green energy production with enough rooftop solar panels to power the shelter itself, and a smart design to collect rainwater; an electricity storage system to accumulate power when solar production is in excess either at the shelter level, or at the district level; an underground electrolyser to convert rain water and electricity into hydrogen, to power a public vehicle fleet**.**



French City Brain Use Case 3. Environmental quality. French Dream Town will deploy IoT in public spaces and infrastructure: in adaptive traffic control, in smart metres, in environmental monitoring, in resource management.



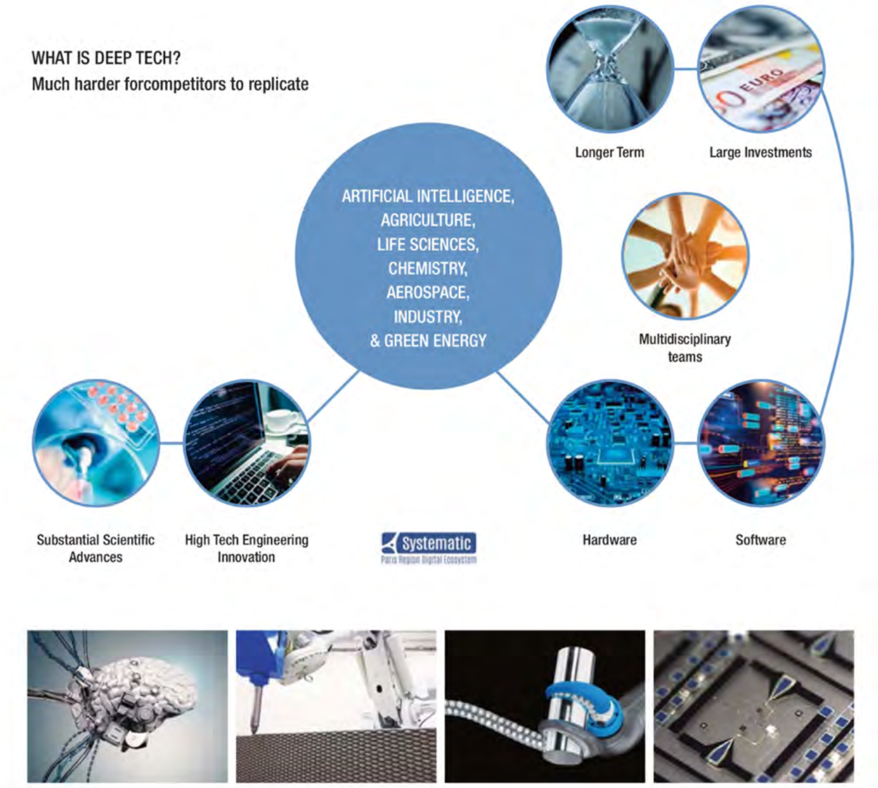
Source: Optiva Darna, Fadwa Sube.

French City Brain Use Case 4. Safe city communication network. French Dream Town has developed a safe city telecommunication network. Telecommunications are an essential step to exploit services based on IoT. Cities and districts should consider reinforcing resilience by deploying their private telecommunication infrastructure to support critical applications such as safety, mobility or energy management. This creates value by offering a secure and flexible wireless network, dedicated to public or technical services; and by reducing deployment costs and mitigating cyber security issues.

French Dream Town has created a secure and flexible wireless network, dedicated to public or technical services. Source: Optiva Darna, Fadwa Sube.

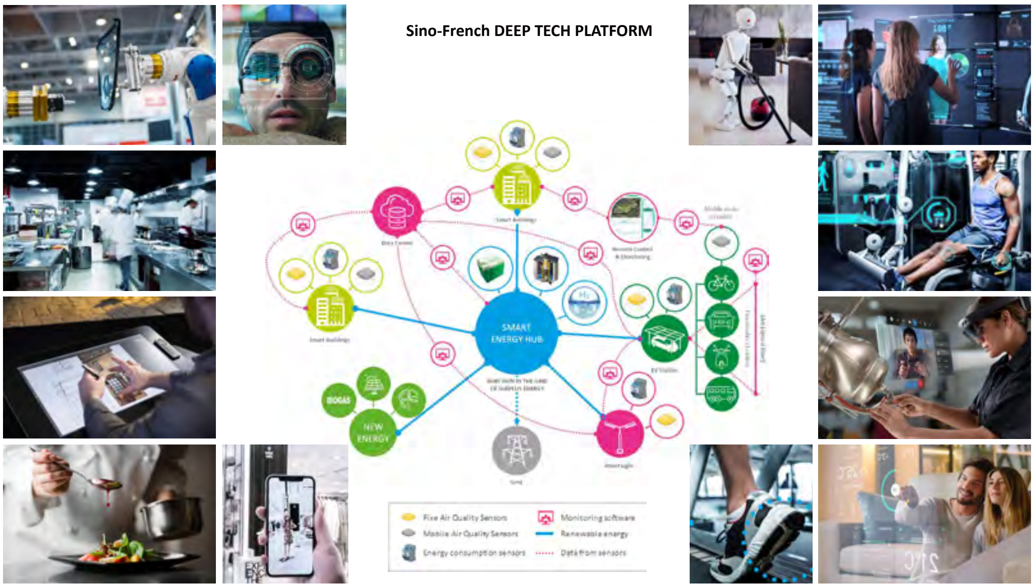
Integrated Smart Creation, Production And Lifestyles

Finally, French Dream Town is an innovation space[28] with a focus on cutting-edge technologies. Public-private partnerships are essential since this city does not only focus on solving urban problems but also on spearheading new industries. French Dream Town is a Deep Tech creative hub. It is the heart of an ecosystem where Franco-Chinese multidisciplinary teams will work to co-develop concepts, solutions, and products for sustainable uses of digital technology and AI in education, bio genomics and health.



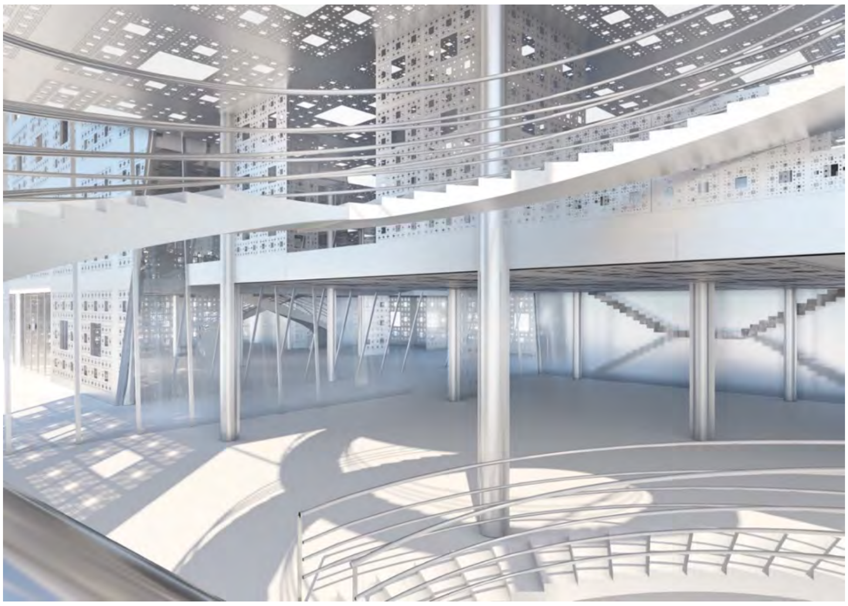
Source: Systematic and Optiva Darna, Fadwa Sube.

[28] Few smart cities are innovation spaces. The Korean Research Institute for Human Settlements (KRIHS) emphasises that new types of smart cities have emerged as a way to establishing innovative industrial ecosystems. However, only 3 out of the 60 smart cities classified by KRIHS are innovation spaces (KRIHS 2018).



French Dream Town integrated tech and lifestyle concept. Source: Optiva Darna, Fadwa Sube.

People are at the centre of French Dream Town project. Creative pedagogy will be at the heart of French Dream Town's education and training platform. French Dream Town will design and develop innovative products with intelligent automation capabilities. French Dream Town will also launch a series of IoT products for healthcare and for fitness including, among others, trackers that monitor all major activities – walking, running, swimming, sleeping, etc. —; and are fully customizable. French Dream Town will develop a unique off-line/online AI experience in its innovative AI Experience Centre.



AI Experience Space in French Dream Town, Hangzhou. Design: Serge Salat. Image: Okenite.

The neighbourhood will see its activities and programmes reshape over time. The functions may fluctuate, be reconverted or transformed as technology evolves. Catering spaces, 'cook labs', 'body labs' and 'tech labs' presenting cutting-edge innovations are designed as investigation tools to test for oneself. These experiences will sometimes be virtual, often real and always assisted or enhanced by new digital technologies. The whole constitutes a true ecosystem of life, hedonistic and technological, where one can learn, discover, eat, work, experiment.

PLAN FOR SEAMLESS MOBILITY

Connecting The Community Is The Foundation Of Civic Life

Mobility is the lifeline of neighbourhoods. It enables economic, social and cultural exchange and links communities to the city and region. Safe, attractive and well-connected places invite citizens of all ages, income and abilities to participate in community life. Connectedness ensures that all residents can fully enjoy their public realm, local parks, health and education, libraries and other civic assets. It creates spontaneous chances to run into a neighbour, learn about a local event, or interact with people from diverse backgrounds and perspectives. Sustainability implies putting people back at the heart of the mobility system, prioritizing human health and experience over traffic dominance.

Mobility networks make cities what they are – linking communities, opening up opportunities and establishing the conditions for economy to flourish. The transport system also shapes inhabitants' everyday lives – how much physical activity they do, how long and pleasant their daily journeys to work, to school and around town are, and even where they choose to live. Careful planning can enable individual decisions to converge in a way that creates healthy places.

The main aim of a sustainable attitude towards transport is first to diminish the need to travel. Second, it is to provide alternative modes with associated lower CO_2 emissions than the private car. The success of a transport system relies upon minimizing people's dependency on cars in favour of increased walking, cycling and public transport. Zurich for instance has restricted parking spaces for alternative means of transport to cars: 450 kilometres of streets are devoted to public transport and 340 to cycling lanes. In town, bus or tram stops are every 300 metres on average. A shift from the car will address many health problems. It will reduce inactivity and clean up the air. It will eliminate the blight of street danger. It will limit the community contribution to climate change and develop attractive local environments. Mobility is crucial to unlocking neighbourhoods' potential – rail, bus, cycling and walking links are all necessary.

Walking and cycling integrated with public transport in London. Source: Mayor of London 2018.

London Mayor's Transport Strategy[29], for instance, can be summarized as follows

- **Ensure that by 2041, 80%of all trips in London are made on foot, by cycle or using public transport and that London's air quality is improved.** The Strategy is underpinned by the Healthy Streets Approach. This framework puts human health and experience at the heart of planning the city.
- **Vision Zero – that by 2041, all deaths and serious injuries will be eliminated from London's transport network.**

Air quality and climate change are such pressing issues that mobility systems should seek to address and overcome their adverse effects. London, for example, aims all new taxis to be zero emission from 2018 and all new Private Hire Vehicles (PHVs) from 2023. All new buses should be zero emission from 2025, all new cars and vans from 2030 and all other vehicles from 2040. This would mean that London's entire transport system would be zero emission by 2050[30].

Transport has a role to play in delivering sustainable growth that satisfies the following principles

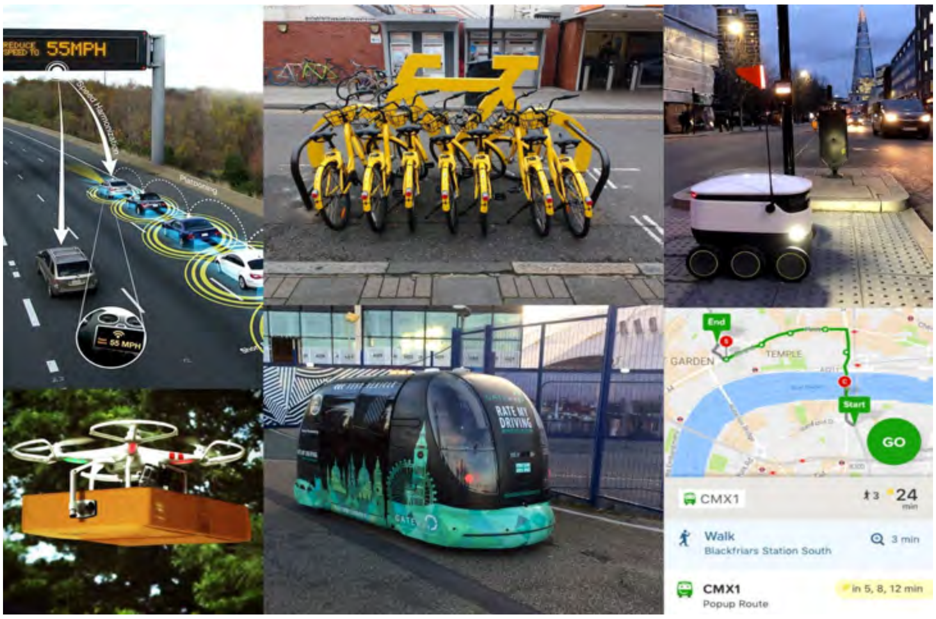
- Good access to public transport.
- High-density, mixed-use developments.
- People choose to walk and cycle.
- Car-free place.
- Inclusive, accessible design.
- Safe travel.
- Carbon-free travel.
- Efficient freight.

The mobility world is changing

Within the timescales of transportation planning, shifts in consumer behaviours, lifestyles and technology could have a profound effect on the way cities work. New economic models based on shared access rather than private ownership will continue to evolve, and new technologies and increasing digital connectivity could significantly change the way people move, live and work.

Four trends are transforming mobility in cities.

- **Sharing**: car-share fleets, e-hailing services, on-demand van and minibus transport, and freight load-pooling.
- **Electrification.**
- **Connectivity and Internet of things (IoT)** enable communication between vehicles and within the broader transport infrastructure.
- **Autonomy and Artificial Intelligence (AI)** enable Self-Driving Vehicles.



A networked system with a variety of digitally connected options in London. Source: London Assembly 2018.

[29] Mayor of London 2018.

[30] Mayor of London 2018.

The four transformative trends reinforce each other as they develop.

- Connected and autonomous technology reduces the cost of shared mobility solutions such as e-hailing services, which could operate without drivers or dispatchers.
- Electric vehicles have lower total cost of ownership than fossil fuel ones, making electrification particularly attractive for shared mobility and autonomous delivery services.
- Connectivity between cars and infrastructure provides autonomy and a whole suite of solutions that can improve traffic flow, including real-time routing away from congestion and smart traffic lights.

Engaging with these trends, mobility will evolve towards a **seamless system** in which the boundaries among private, shared, and public transport are blurred, and travellers have a variety of clean, cheap, and flexible ways to get from point A to point B.

Looking at the transport system as a single, connected whole is the key to addressing mobility challenges. Planning for seamless mobility comprises six main pillars.

DEVELOP AN INTEGRATED APPROACH
PHASE OUT CARS AND PARKING
IMPROVE WALKING EXPERIENCE
IMPROVE CYCLING EXPERIENCE
PROMOTE PUBLIC TRANSPORT
PREPARE FOR SEAMLESS CONNECTED AUTONOMOUS MOBILITY

DEVELOP AN INTEGRATED APPROACH

A transportation plan should focus on moving people, not cars. It should involve many stakeholders to ensure meeting mobility needs. The more travel options are available to people, the more likely they can pick a sustainable and healthy choice. 'Mobility-as-a-Service' is a fully connected system. It integrates various modes with information and payment functions into a single service. Recent services allow customers to purchase monthly subscription packages giving them access to public transport and private taxi and bike hire schemes.

Systems integration involves

- Providing people with flexible, efficient, integrated and user-oriented mobility services.
- Increasing collaboration across mobility stakeholders.
- Implementing Mobility-as-a-Service to trigger a move from personal ownership towards shared transportation solutions.

Objectives are

- Reduce the demand for total motorized transport by creating jobs where people live and by developing well-designed urban places.
- Manage demand.
- Promote 'low-emission' modes such as walking, cycling and public transport.
- Use the most efficient fuel-vehicle technology system possible for all journeys.
- Speed up the shift to electric vehicles.

Streets must transport cars, buses, trams, cyclists and pedestrians in a safe and equitable manner. Very few travel elements have to be purely mono-functional. This approach reduces the costs of supplying infrastructure and services and improves the resilience of systems by providing backups.

An integrated approach is implemented through the following steps[31].

- Evaluation of the gaps and areas of monofunctional travel service through asset mapping.
- Development of plans for pedestrians and cyclists that promote connectivity to a regional public transport system.
- Improvement and clear the access to local buses to and from regional stations.

[31] Eitler et al. 2013.

Cycling as a lifestyle in Viikki, Finland. Photo: ©Françoise Labbé.

Integrated mobility systems in Bo01 Malmö. Photo: ©Françoise Labbé.

In Bo01, Malmö, for example, the sustainable mobility strategy begins with diminishing dependence on the car. Offering a full range of services and recreational activities in the community reduces the demand for trips outside the neighbourhood. With walking and cycling, public transport is the strategy backbone. Bus stops are located so that no residence is more than 300 metres from a bus stop. Bus frequency is every six to seven minutes. All vehicles run on electricity and natural gas. All residents have access to mobility management information displayed on apps and at the bus stops. Underground structures provide parking. Street parking is limited. The initial parking ratio was 0.7 spaces per unit to stimulate walking, cycling and the use of public transportation. Inhabitants are also encouraged to join a car-sharing service made up of green vehicles.

Public transport plan for Bo01. The plan ensures that no residence is more than 300 metres from a bus stop. Source: City of Malmö, 'Design Principles'. Redrawn by Mahammad Mornin.

In Kronsberg, Hannover, the new tramline is the backbone of the transport system, offering a 20-minute link between Kronsberg and the Hannover city centre with service provided every 8 to 12 minutes. Five stops at 300-metre intervals make no resident more than 400 metres away from a stop.

Vauban, Freiburg, has developed a comprehensive concept of car-free living that can be summarized as follows[32]

- Priority is given to pedestrian, cyclists and public transportation.
- All schools, businesses, jobs, shopping centres, food cooperatives, and recreation areas are within short walking and cycling distances (less than 10 minutes) from residential zones.
- No parking – only drop-off (including deliveries) and pick up are allowed at home doorsteps. Parking for residents' cars is available in community facilities nearby at the periphery.
- The speed limit on the neighbourhood's main street is 30 kilometres per hour and in residential areas is restricted to walking speeds of 5 to 7 kilometres per hour.
- Car sharing is available.
- Access is provided to public transport – both tram and buses. The tram connects in 10 minutes to downtown Freiburg with frequencies every 8 minutes.

[32] Fraker 2013.

Process for integrated mobility

- **A strategic vision** decides objectives and seeks the alignment of all key public and private stakeholders. This will ensure a balance between vision and project feasibility.

- **Mobility supply management** extends transport offer with views to 'delivering solutions' rather than 'delivering transport'. Cities enter in partnerships and alliances with third parties, offering user-friendly multimodal solutions that meet everyone's needs.

- **Mobility demand management** defines ways (incentives/penalties) to encourage people to match their behaviour to the mobility mode adopted.

- **Funding** ensures the financial viability of public transport and its operators. Assessments must be made in three areas.
  - opportunities to derive additional revenues from aggregation of third-party services**.**
  - growth in passenger numbers**.**
  - revenue collection from indirect beneficiaries of public transport.

Optimize demand

Optimizing demand changes how passengers use the public transport system

- by decreasing the demand for public transport
- moving trips away from peak times
- shifting trips to shared[33] transport modes

Tools to optimize demand

- dedicated lanes for shared vehicles
- new modes to access rail stations
- move some traffic to off-peak hours. If people take trips when others do not, the same infrastructure and rolling stock can carry more travel with less congestion.
  - Shift government or academic business hours to spread the rush hour over a longer period.
  - Adopt congestion pricing[34].
  - Allow off-peak deliveries[35].
- Deploy intelligent traffic systems.
  - Lights that detect traffic and communicate with each other to minimize wait times and maximize movement.
  - Dynamic lane allocation that shifts lanes in the direction with more traffic.
- Employ smart parking technology. Digital links between vehicles and infrastructure inform users on available parking spots. This reduces the time required to find a space.

Optimize mobility options

- **Plan an integrated system** combining public, private and multiple modes.

- **Link with digital technology different modes, timetables, ticketing and payments across transport services.** This makes it easier to switch between options and improves the user experience. New technology and business models such as Mobility-as-a Service make the planning and execution of multimodal journeys easier and shift people away from the private car.

[33] With shared mobility, transport services and resources are shared among users, either concurrently or one after another. Public transport as well as newer models such as car-sharing, bike-sharing and ride-sharing, are all types of shared mobility.

[34] Used by cities such as London, Milan, and Singapore, congestion pricing is a system in which vehicles pay to enter busy urban areas at certain times.

[35] Goods transport accounts for almost 20% of congestion. Source: 2015 urban mobility scorecard, Texas A&M Transportation Institute, August 2015, tamu.edu.

- **Expand mobility options**[36].
    - Develop multi-use trails and greenways.
    - Develop a network of safe, continuous bicycle lanes and infrastructure.
    - Enhance frequency of public transport service, strengthen reliability, and make stops more comfortable and accessible.
    - Adopt policies to ensure road improvements address the needs of pedestrians, cyclists, and public transport travellers.

Enhancing the offer does not necessarily mean adding infrastructure and rolling stock. The traditional approach to optimizing supply is to build more roads, bridges, railways and other infrastructure, but this can be difficult and costly. Instead, tools can increase the exploitation of existing infrastructure.

- intelligent traffic systems.
- smart parking.
- condition-based and predictive maintenance.
- automated rail.
- advanced rail signalling.
- preparing for connected autonomous vehicles by setting standards for car communication.

Autonomous operation and advanced signalling can reduce space between trains and move more people on the same rails. Condition-based and predictive maintenance mean collecting performance data and using statistics to identify and fix problems before they can cause breakdowns.

CASE STUDY: CHANGING A COMMUNITY LIFE WITH INTEGRATED MOBILITY IN MEDELLÍN[37]

Medellín's transformation main driver has been an innovative transportation system that provides access to jobs, education opportunities, and civic and recreational spaces for poor hillside favelas residents. Metro de Medellín is a network of clean and efficient train cars that serves more than 500,000 passengers per day. Funded by a public/private partnership, the transportation network includes cable cars and a 385-metre outdoor escalator. It transports favela residents up and down steep hills. It saves hours of travel time to reach jobs, health care, schools and services. The metro's public transport hubs have spurred new investment in infrastructure, services and amenities, such as hospitals, many of which are integrated into the metro infrastructure. The public transport system benefits from connections with public green spaces and pedestrian paths, a self-service bicycle programme linked to universities and a carpooling programme involving more than 170 institutions.

[36] Adapted from Center for Active Design 2018.

[37] This box draws on ULI 2013.

PHASE OUT PARKING

Streets should be for active travel and social interaction, but too often they are places for cars, not people. Cars take up a lot of space compared with the number of people they can move around, and excessive reliance on this mode of transport has made streets congested. This has huge impacts – causing pollution, making streets unpleasant places to be and delaying public transport travel. It also reduces the efficiency of freight and commercial journeys – the trips that keep the shops stocked and businesses running.

More than 30,000 square kilometres of land is devoted to parking in Europe. In the US, that's up to 27,000 square kilometres of prime land. As much as 65% of the total impervious surface cover in the American landscape is areas designed for cars including, but not limited to, streets, parking lots, and driveways. Motor vehicles are parked 95% of the time, on average. All those parked vehicles take up a lot of city land, much of which is highly valued and sought after. Vehicle parking is blighting, and contributes to dispersed development, increasing travel distances. Each parking spot consumes from 15 m^2 to 30 m^2 of land, and the average motorist uses two to five parking spaces daily[38]. The area devoted to parking lots is widely seen as disrupting a walkable urban fabric. Parking facilities absorb land and resources, inhibit the functioning of natural systems, create dead gaps in what otherwise might be vibrant commercial neighbourhoods. Parking lots tend to be sources of water pollution and exacerbate the urban heat island effect because of their extensive impervious surfaces.

Repurposing road space for bike lanes or bike parking revitalizes communities. Treating street space as a valuable public asset, by reclaiming it from cars, can lead to much better land uses.

Parking policies in leading sustainable cities

Parking policies in leading sustainable cities are part of broader mobility targets. While London, Stockholm, Singapore and a few other cities have managed to implement congestion charging to reduce motor vehicle use, more are turning to parking restrictions.
In sustainable cities, parking policy has three main objectives.

- Reducing congestion and greenhouse gas (GHG) emissions.
- Redeveloping public realm. Removal of on-street parking from neighbourhoods and shopping streets has become a signature feature of many sustainable cities. This is often a boon for business, too. Shops within the pedestrian precincts generate more income than those outside.
- Reducing the amount of on-street car parking encourages the use of other transportation modes by transforming former parking spaces into bicycle paths or wider walkways. Sustainable neighbourhood schemes push parking to peripheral locations, while giving transit passengers and cyclists more convenient access to popular destinations than private motorists.

Amsterdam, for instance, announced in March 2019 that it would systematically decrease inner-city parking spaces. The city planned to reduce the number of people allowed to park in the city by around 1,500 a year, with a target of eliminating up to 11,200 parking spots by 2025[39]. The city plans to invest freed space in more bike parking spaces, wider sidewalks and trees. Cycling lanes and pedestrian zones make now the greater part of streets. Bicycles have priority over cars in the town centre to facilitate trips and promote their use[40]. Copenhagen is repurposing public spaces. It has transformed its city centre by creating high-quality

[38] A parking lot needs large space, around 25 square metres per parking spot. This means that parking lots usually need more land area than for corresponding buildings for offices or shops if most employees and visitors arrive by car. This results in covering large areas with asphalt.

[39] Source: Benchmark for parking policies in large urban agglomerations (in France and Europe). https://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/atoms/files/rapport-stationnement-benchmark1.pdf

[40] ITDP 2011.

pedestrian districts and bicycle paths by eliminating hundreds of parking spaces. In parallel, the authorities have increased the number of off-street parking spaces to partly compensate for the reduction in on-street spaces. In 2010, they built three underground car parks in the town centre; that is 880 new off-street parking spaces[41].

Parking Policies in European Cities[42]

	Amsterdam	Antwerp	Barcelona	Copenhagen	London	Munich	Stockholm	Zurich
Parking provision								
On-street metered parking + off-street metered parking	X	X	X	X	X	X	X	X
Residential parking permit	X	X		X	X	X	X	X
Park-and-ride facilities	X					X		
Car-sharing	X			X	X			X
Self-service bike sharing		X	X		X		X	
Regulations								
Public-private partnership		X					X	
Reinvestment of revenue in sustainable modes of transport	X	X	X					
New technologies								
Charging terminals for electric cars	X		X	X	X		X	
Real-time display boards indicating free spaces in off-street car parks			X			X		X
Phone payment	X	X		X	X		X	
Cutting edge technology	X	X					X	

These policies have been effective. In ten years, the number of households owning a car in Paris decreased from 44% to 36%. In dense and mix use Paris central districts, the percentage of households that do not own a car is even higher. In Paris 1st District for instance, three quarter of households do not own a car[43]. Only 13% of households have a reserved spot for parking. Most people living in those 2 to 4 square kilometres 'arrondissements' also work in the same one, avoiding any dependency on cars. For instance, in Paris 1st District (182 ha), 73% of people live and work in the district. In Paris 1st District, people travel to work by walking (20.4%), cycling (4.3%) or public transportation (56.8%). Only 6% commute by car[44]. London also has low levels of car ownership. In 2011, as many as 70% of households in London did not own a car. This downwards trend will continue. In Amsterdam, only 22% of journeys take place by car. As an outcome of phasing out cars, in Stockholm town centre 67% of trips use eco-friendly methods, 25% by public transport and only 8% by car.

Parking maximums

Historically, most cities required developers to build a minimum number of new parking spaces. Residential buildings had to include at least one, if not more, parking spaces per residential unit, and commercial developments had to build a minimum number of parking spaces per square metre depending on the building use. Sustainable cities today are suppressing these parking minimums in town centres and placing new ceilings on the number of new parking spaces they can build. Paris abolished parking minimums and several other cities established zone-based maximums.

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41 Source: Benchmark for parking policies in large urban agglomerations (in France and Europe). https://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/atoms/files/rapport-stationnement-benchmark1.pdf

42 Source: Benchmark for parking policies in large urban agglomerations (in France and Europe). https://www.strategie.gouv.fr/sites/strategie.gouv.fr/files/atoms/files/rapport-stationnement-benchmark1.pdf

43 Source : INSEE. https://www.insee.fr/fr/statistiques/2011101?geo=COM-75101

44 Source : INSEE. https://www.insee.fr/fr/statistiques/2011101?geo=COM-75101

CASE STUDY: REDUCING CAR PARKING IN LONDON

BedZED[45] (Beddington Zero Energy Development)

As part of the Green Travel Plan, negotiations with the local authority in BedZED (Beddington Zero Energy Development) in the UK led to a 50% reduction in the usual parking standard. Restricting the car-parking provision has released more land for and fostered a higher development density. Green upgrades have been financed by the rewards resulting from this 'planning gain'. Calculations based on comparing BedZED to a more conventional volume-housebuilder solution for the same site, suggest that the reduced space required for parking and roads has contributed towards enabling over 100% more footprint to be built.

Parking Maximums in the London Plan

The London Plan (March 2016) makes the following references to car parking

Residential. All developments in areas of good public transport accessibility in all parts of London should aim for significantly less than 1 space per unit. Twenty percent of all spaces must be for electric vehicles with an additional 20% passive provision for electric vehicles in the future.
Retail. Developments with a retail food provision over 2,500 m^2 may provide a maximum of 1 space per every 18 – 25 m^2 of gross floor space.
Offices. In inner London locations, the maximum parking that may be provided is 1 space per 600 - 1,000 m^2 GIA**.**
Industrial. Parking for commercial vehicles should be provided at a maximum of one space per 500 m^2 of gross floor space.
Hotel. Although no maximum standards are set for hotels, on-site provision should be limited to operational needs, parking for disabled people and that required for taxis, coaches and deliveries/servicing. Provision should be consistent with objectives to reduce congestion and traffic levels and to avoid undermining walking, cycling or public transport.

Parking Maximums in London Sustainable Neighbourhood Regeneration[46]

Old Oak and Park Royal, London.

[45] Source: BioRegional Development Group 2002.
[46] Source: Mayor of London 2018b.

Old Oak and Park Royal will be high density and deliver a mix of uses, including significant local amenity for workers and residents alike. In the future the area will be one of the best-connected locations in the UK with new stations for HS2, Crossrail and 2 London overground stations (Hythe Road and Old Oak Common Lane).

Proposals

a) Old Oak

- Limiting car parking to 0.2 spaces per residential unit in the early years of development, reducing to car free when transport investment is committed.
- Securing zero car parking for non-residential developments except for blue badge holders.

b) Park Royal

- Limiting car parking to 0.2 spaces per residential unit in the early years of development, reducing to car free when transport investment is committed.
- Allowing limited car parking for non-residential development according to access to public transport and operational or business needs.

Design recommendations for parking lots

- Place parking lots behind buildings versus along the street.
- Use landscaping on the periphery and within parking areas to soften the appearance from the street.
- Break up expanses of parking with landscaped islands and planted strips, which include shade trees and shrubs. Such landscaping provides a canopy cover and reduces the urban heat island effect in the summer. Landscaping breaks up the visual impact, making the parking lot feel smaller and less overwhelming.

Design recommendations for parking structures

Parking structures are usually poorly integrated in the urban fabric. Their visual prominence has adverse impacts.

- Locate them behind buildings and not in front of buildings.
- Locate them inside the blocks.
- Screen them with landscaping.
- Integrate parking structures with their surroundings through scale, materials, colours, and style. Meld the parking structure with the scale and character of adjacent buildings and provide visual breaks to hold the interest of walkers passing by.

IMPROVE WALKING EXPERIENCE

Walking and cycling alternatives accessible and appealing to neighbourhood inhabitants is crucial for diminishing car dependency. This requires improving street environments to make walking and cycling the most attractive options for short journeys. This approach will reduce health and economic inequalities.

New technology and platforms should make choosing cycling and walking easier by

- Showing routes and timings.
- Always offering active travel options for short trips.
- Integrating walking and cycling into the choices for longer multistage journeys.

Street design determines the extent of active mobility options. It may encourage walking by making streets feel safer and more visually interesting. A comfortable, tree-lined sidewalk along a thriving mixed-use street with small blocks will welcome people to walk. Attractive streets have the following positive outcomes.

- Encourage active journeys. Walking or cycling as little as 20 minutes a day is enough to remain physically and mentally healthy. Active travel has a vital role to play in solving chronic diseases issues. Most people can get the physical practice they need to stay fit by walking or cycling as part of trips they are already making.

- Reduce car use and lower harmful emissions.

- Improve the community's resilience to climate change and Urban Heat Island Effect thanks to the trees and other greenery that make streets pleasant places to be.

- Enhance safety thanks to 'eyes in the street' in environments that are busy with people, rather than cars.

- Help older and disabled people access the city.

- Strengthen communities.

- Attract local businesses. Making streets work for people provides huge economic benefits through revitalizing the neighbourhood, and by freeing up areas for the essential freight and commercial journeys that keep enterprises functioning.

Improving the experience of being on streets is the most effective way of encouraging more people to walk and cycle. When designing new streets or upgrading existing ones, consider the uses of the whole street, from facade to facade. Walking, cycling, and public transport should be prioritized, taking space from less efficient general traffic where required to minimize conflicts with active sustainable modes.

Design to give priority to pedestrians

Ample pedestrian and cycling realms in London streets. Source: Mayor of London 2018.

People walk with a goal or participate in other activities such as playing, socializing, shopping or just sitting down. Street layouts and details should be configured to allow walkable access to local amenities for all street users. They should encourage positive interaction for all members of the community. Pedestrian routes should be primarily on sidewalks along streets. The minimum width for a sidewalk is about 4.50 metres, enough to leave a comfortable clear area for pedestrians and a 1.6-metre band next to the kerb that can offer trees and street furniture. Six metres is the minimum that provides room for a sidewalk cafe.

Designing walkable streets and other public spaces enhances the quality of urbanity. Observing people motion reveals the different effects at work: how people move, especially walking, is not only a matter of the simplest and most obvious way. It is influenced by:

- variety and interest.
- safety.

- light and shade.
- commercial activity.
- Landscape.

Vibrant street life in Copenhagen. Photo: © Françoise Labbé.

- **Create a comprehensive network** that allows residents to walk anywhere. Fill gaps in the sidewalk continuity and require new developments to provide secure pedestrian connections to the surrounding community.

- **Strengthen neighbourhood links with trails** that serve transportation and recreational needs.

- **Calm traffic** to reduce vehicle speeds and improve safety. For example
    - enhance crosswalk markings.
    - extend kerbs.
    - landscape medians.
    - narrow travel lanes.
    - introduce speed bumps – particularly in areas with high crash rates or heavy traffic
    - Include special pavers to highlight pedestrian and slow traffic.

- **Provide sidewalk amenities** such as benches, trees, and lighting to support comfort. Seating allows people to stop and rest. Trees beautify and provide shade. Pedestrian scale lighting aids night-time visibility.

- **Design buildings and sites to prioritize pedestrians and create curiosity along the sidewalk.** Orientate main entrances and signage toward sidewalks and pedestrian paths. Encourage shops to activate their frontages, for example integrating seating or sidewalk cafes.

- **Maximize transparency of facades** at ground level – for instance, with windows – to increase visual interest and promote walkability.

- **Provide maps and signage for pedestrians** – with mileage and key destination points in the area – to help people feel at ease about walking and biking.

Check list for enhancing safety and encouraging walkability along streets

—Street connectivity
—Land-use mix
—Residential density
—Presence of trees and vegetation
—Frequency and variety of buildings
—Entrances and detailing along street frontages
—Sightlines and visibility to destinations or intermediate points
—Pedestrian routes must be part of shared multimodal corridors
—Street widths should be appropriate
—Devices should calm speed

—Large streets should not be car-oriented arterials. They should be boulevards with median plantations and trees and between half and two thirds geared at pedestrian speed and scale.

—The facades of buildings (doors and windows overlooking habitable rooms) must be on the streets

—Public lighting for night security

—Allowing cars in neighbourhoods at night can create more activity and provide natural surveillance

—Ensuring that routes are convenient to users of all abilities

Enhance Safety with Street Geometry

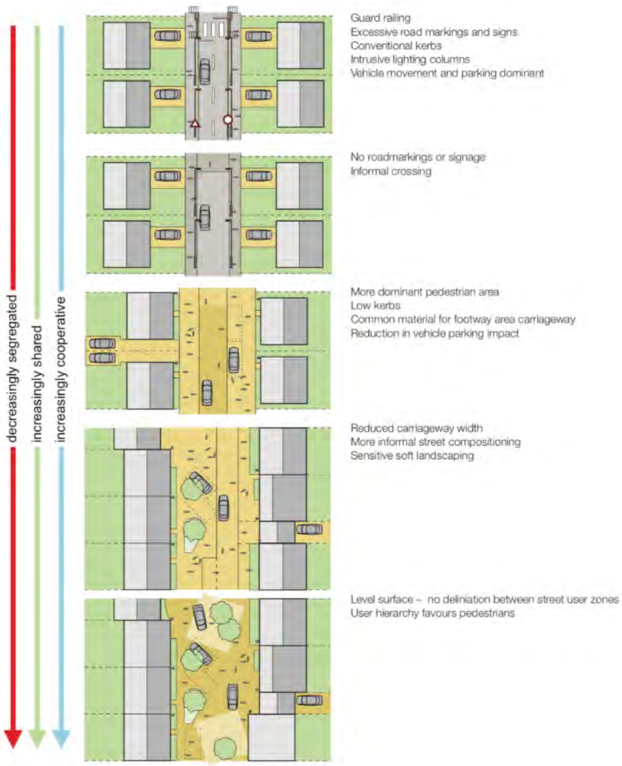
Strategically arranging parking spaces can help make other street users more comfortable. In Zurich, alternating parking spaces on two sides of a narrow street act as a chicane that slows vehicle speeds. Amsterdam has zones called woonerfs that use parked cars to create a winding passage which forces vehicles to move at a pedestrian's pace. Paris and Copenhagen have bike lanes protected by parked cars – these act as a barrier between the cyclists and moving traffic. Copenhagen and Antwerp have play-streets that allow children to safely spend time on the street without the threat of being hit by a car – trees, benches, and other physical obstructions cue vehicles that they are guests in the space.

Make Streets Shared Spaces

Adding the width of lanes for each mode can result in wide and inhospitable streets. Various modes may share the same space, perhaps at distinct times of the day or different days of the week. Cars may be allowed in an area in the evening. Bus lanes may be used at peak times. Shared corridors permit efficient use of space, providing choice and creating activity on the streets. This will help make them safe. Stops and platforms can be ideal places for small shops.

Shared space schemes for London streets. Source: Mayor of London 2018.

Design can make streets shared spaces accessible to both pedestrians and vehicles and designed to enable pedestrians to move more freely. Traffic calming measures and minimal use of road signs, road markings and traffic management features can facilitate achieving this outcome. With less or no traffic management devices giving clear evidence of priority, motorists are encouraged to recognize the space as different, to drive more slowly and to react directly to the behaviour of other users (including other motorists).



Increasing proportions of shared space. Source: The Government of Scotland 2010.

A key shared space feature is a level surface. Kerb or level differences do not segregate the street. The absence of defined zones indicates that the street is to be shared equally by all. Motorists are expected to adapt their behaviour to that of other users, driving slowly and giving way when necessary. Without a formal roadway, experience shows that motorists tend to drive more carefully and negotiate the right-of-way with pedestrians in a more accommodating way. However, shared spaces, and level surfaces can pose problems for people with disabilities. Level surface schemes should thus include an alternate means to help visually impaired people navigate.

Design Junctions for Pedestrians First

Junctions should respond to the context and urban fabric. Car standards should not dictate the street design. Pedestrian movement lines should be as straight as possible at junctions. Small corner radii minimize the need for pedestrians to deviate from their desire line. Junction design also affects the way motorists interact with cyclists. It should promote low speeds of motor vehicles. This includes short corner radii and vertical deflections.

Adopt a universal design approach[47]

Mobility should facilitate ease of use for people of all ages and abilities. This requires removing barriers on streets, sidewalks, and other public and private spaces. Universal design interventions include wide, accessible, and unobstructed routes with well-maintained, non-slip pavement. Ramps and elevators should be available to provide an alternative to stairs. Universal design principles and neighbourhood examples are summarized in the table below[48].

[47] Also known as barrier free planning, inclusive design and design for all.

[48] Adapted and modified from: Forsyth et al. 2017.

Principle	Neighbourhood example
Equitable use The design is useful for people of diverse abilities.	▪ Large tree-shaded sidewalks with well maintained and even pavement; separated, continuous and connected bike lanes; safe crosswalks. ▪ Handrails, seating, and street furniture. ▪ Gradients, incline no more than 6%. ▪ No stairs or obstructions in paths ▪ Well-maintained non-slip paths.
Flexibility and diversity in use The design allows many preferences and abilities.	▪ Public space and streets which accommodate several activities beyond mobility, such as playgrounds, programmed community events, scenic walking paths.
Simple and intuitive use The design is easy to understand, regardless of the user's experience, knowledge, language skills, or current concentration level.	▪ Clear and accurate wayfinding and directional signs in multiple idioms if those are in usage in the community.
Perceptible information The design conveys necessary information effectively, regardless of ambient conditions or people sensorial abilities.	▪ Signs, wayfinding, and crosswalk engage several sensory modes (for example visual, auditory, tactile). ▪ Textures and sound for the blind. ▪ Using images, sounds, and changes in horizontal surface textures to communicate.
Tolerance for error The design minimizes hazards and adverse consequences of accidents.	▪ Disaster evacuation plans. ▪ Connectivity of street pattern to ensure access for emergency vehicles.
Low physical effort People can use the space efficiently and comfortably with little fatigue.	▪ Affordable and accessible public transport. ▪ Universal design features on rolling stock and stations. ▪ Door to door public transport schemes. ▪ Wide and well-maintained sidewalks with kerb cuts.
Size and space for approach and use The design provides appropriate size and space regardless of the user's body size, posture, or mobility.	▪ Wide doorways. ▪ Motorized door openings. ▪ Ramps. ▪ Wheelchair entrances. ▪ Pedestrian amenities such as benches and public toilets.

Reduce traffic speed

Design should influence driver behaviour. It should foster vehicle speed decrease to levels appropriate for the local context. Designers should create streets that reduce from the start vehicle speed with layouts rather than with traffic calming measures added at the end. Providing walking or cycle routes separated from automobile traffic should only be a last resort action. The presence of pedestrians has an impact on diminishing traffic speeds. Speed control devices at intervals of about 60 to 80 m achieve speeds of 30 kilometres per hour or less. Straight and uninterrupted streets should be limited. Speed restriction should be integrated into the street layout, taking advantage of building alignment, parking, road narrows, landscaping and other design features, rather than to use only vertical deflection[49].

[49] The Government of Scotland 2010.

Traffic Calming Measures by Design[50]

Psychology and perception play a strong part in shaping driver behaviour. Street characteristics and human activity can influence driving speed. Effective features include

• edge markings that visually narrow the road. Drivers will reduce their speed where the edging is textured to appear unsuitable to drive
• buildings in close proximity to the street
• reduced carriageway width
• physical features in the carriageway
• features associated with potential activity in, or close to, the carriageway, such as pedestrian refuges
• on-street parking, particularly when the vehicles are parked in blocks on alternate street sides, either in echelon formation or perpendicular to the carriageway
• the types of land use associated with greater numbers of people, for example shops, schools and places of work
• landscaping

Street dimensions can have a significant influence on speeds. Keeping street lengths between intersections short is efficient.

Reductions in forward visibility foster lowered driving speeds.

Changes in priority/or no priority at junctions disrupt flow and therefore bring speeds down.

Physical features – involving vertical or horizontal deflection can be very effective in decreasing speed.

Materials – can reduce speed by both visual perception and by physical characteristics, such as cobbled surfaces

IMPROVE CYCLING EXPERIENCE

Cycling in Hammarby Sjöstad. Photo: ©Françoise Labbé.

[50] Adapted from The Government of Scotland 2010.

Individual street improvements can change places, but to achieve sustainable mobility aims, it is vital to consider how the wider street network operates as a whole. **Communities need appealing cycling environments and a strategic cycling network across the entire city because making cycling attractive is dependent upon making it easy to do wherever people live, and wherever they are travelling to.**

The key design strategies for biking are

- To keep the pedestrian and cycling network continuous.
- to slow vehicular traffic.

This often involves traffic calming interventions, creating pedestrian and cycling passageways between vehicular traffic routes, and implementing various strategies to make car travel quieter and cycling more direct, quick, and attractive.

Pedestrian and cycling passageways in Hammarby Sjöstad. Photos: ©Françoise Labbé.

Key Actions are

- **Retrofit signage, crossings, furnishings, and plantings; alter travel lanes to prioritize walking and cycling.**
- **Develop a network of safe, continuous bicycle lanes** and related bicycle infrastructure. Fill gaps in bike networks and provide easy access to bike parking and bike share facilities.
- **Where possible, supply bikeways within the street network.**
- **Maximize connections to bicycle networks**, including multiuse trails and greenways.
- **Offer safe indoor bicycle parking** in the form of racks or storage rooms to ensure security and weather protection, and provide outdoor bike racks.
- **Set up a bike-share programme** to give access to bikes for residents or tenants on an as-needed basis, particularly if the neighbourhood does not have access to a larger bike-share network.

CASE STUDY: PEDESTRIAN AND BIKING NETWORKS IN BO01 MALMÖ

Distributing the mail by bike in Malmö. Photo: ©Françoise Labbé.

In Bo01, Malmö, the bike circulation system and the pedestrian network are the key elements of the green mobility strategy. Design gives them priority. The cycle paths are a complete network, marked and connected to the important routes and destinations in the city. The footpaths and sidewalks are built with high-quality materials, including brick, granite and wooden pavers. The ground floors of all buildings are designed with higher ceilings to enable shops and services, activating the pedestrian experience along the streets. Several shortcuts across the blocks allow for a variety of routes and shorten trips.

High quality surface material in Malmö. Photo: ©Françoise Labbé.

CASE STUDY: CYCLING INFRASTRUCTURE FOSTERING CHANGE IN THE NETHERLANDS[51]

Since the 1970s, the Netherlands combined every possible strategy to support pedestrians, cyclists and public transportation: community design, infrastructure and facility improvements, changing pricing incentives, policies and educational programmes. This created a much safer and convenient cycling environment, especially important for women, children and the elderly.

Strategies are

Community design
– Street design and urban form that prioritize cyclists over cars
– Infill and redevelopment systematized over new growth, mixed-use zoning
– Transportation and land-use planning integrated across levels of government and spatial scales
– Cycling and walking facilities required in new suburban schemes

Infrastructure and facility improvements
– Extensive systems of continuously connected separate cycling lanes
– Intersection modification and priority traffic signals
– Traffic calming and low speed limits
– Bike parking
– Coordination with other transport modes and facilities, such as bike parking at traffic stations, bike rentals at traffic stations and 'park and bike' parking lots

Changing pricing incentives
– Tax breaks to purchase a bike
– Higher taxes for automobile ownership and use (sale, parking, licence)
– Access to inexpensive or free bikes via rentals and company bikes

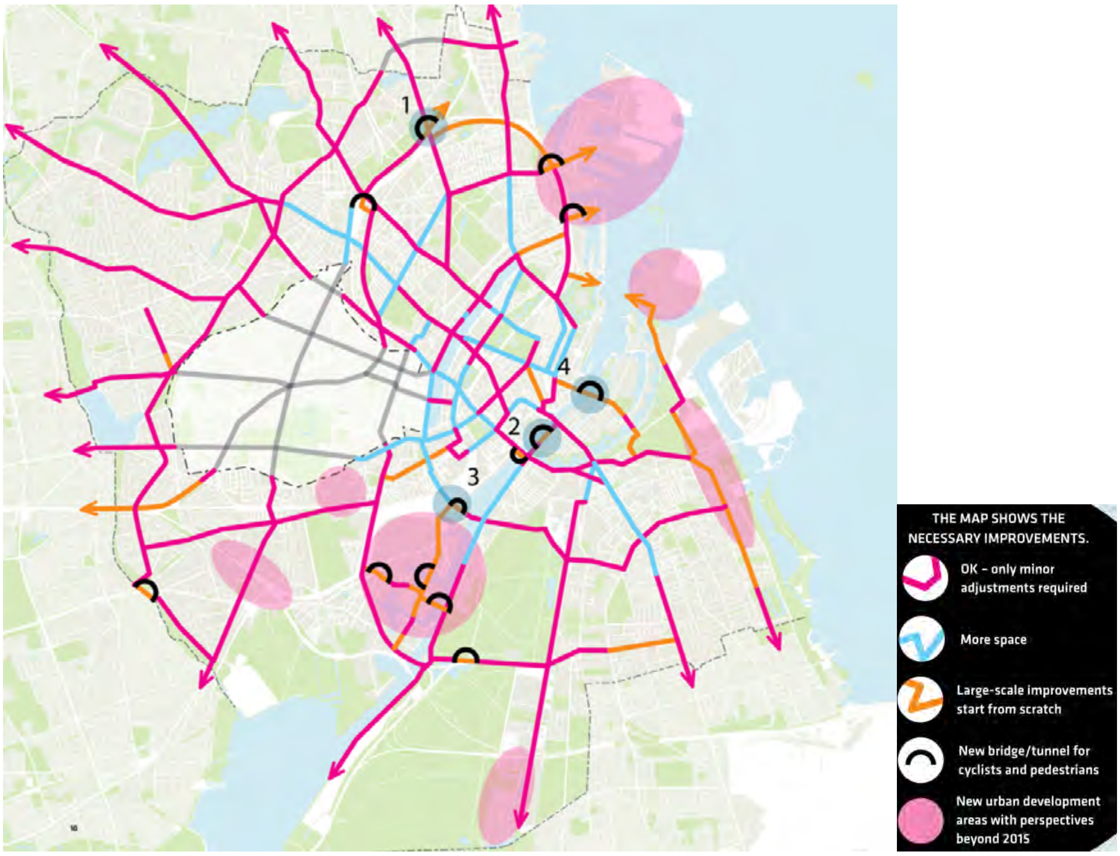
Policies
– Cyclists have legal right of way over motorists (children and elderly especially protected)
– Strict enforcement of cyclists' rights by police and courts
– Public participation in bike planning

Educational programmes
– Traffic education and training for both cyclists and motorists
– Trip planning websites and comprehensive bike maps

[51] This box draws on Forsyth et al. 2017.

CASE STUDY: CONNECTING THE MOVEMENT FRAMEWORK OF BIKE LANES IN COPENHAGEN

Copenhagen goal is to become the first carbon-neutral major city by 2025. As part of this objective, the city aims to be the best world city for cycling. The targeted modal share is 50% cycling for commuting to school or work. Copenhagen's plan includes increasing the capacity of cycle paths to the city centre, to accommodate an additional 60,000 cyclists by 2025. To make cycling the preferred option of its residents, Copenhagen recognizes that journey time is of paramount importance. Forty-eight percent of cyclists in Copenhagen say that the main reason they favour a bike is that it is the quickest and easiest way to get around. To encourage more people to ride, travel times by bicycle must be competitive compared to other modes of transport. Travel time is not only about speeding through the streets, but also being able to choose your pace and access direct routes. Too many brief stops, detours and stretches where overtaking is impossible makes journey times much longer.



PLUSnet cycling network in Copenhagen. Source: City of Copenhagen.

Copenhagen Actions

Travel time

Bicycle Superhighways (network of routes in the capital region). Small shortcuts (200–400 in all, including contraflow on one -way street, shunts).

Large shortcuts (5–8 bridges/underpasses).

ITS on, for instance, routes with Green Waves for cyclists. E-bikes (infrastructure and promotion).

Information about the best routes (signage, GPS solutions). Lower speed limits for cars where necessary, for example around schools.

Better combination of metro/train/bus and bicycles, featuring a bike share programme and better parking facilities at stations. Increased population density.

Behavioural campaigns focusing on signalling and overtaking with care.

Cooperation with the police regarding changing traffic laws, including creating contraflow on one-way streets, and solutions that make it possible to turn right at red lights.

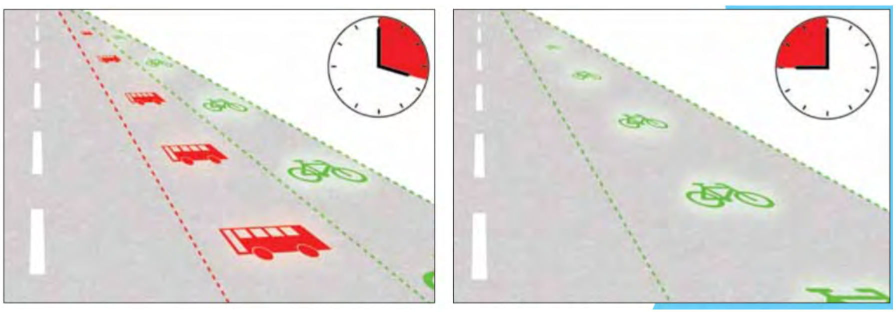
Sense of security
Green bicycle routes.
Crossing redesign (including cycle tracks running right up to the intersection as standard and pulled back stop lines for cars).
New cycle tracks and lanes (30–40 km).
Wider cycle tracks in general (10–30 km).
Painting lanes on wide and busy cycle tracks.
Bicycle and bus streets.
Campaigns related to consideration and behaviour.
Safer routes to schools.
Traffic policy at various schools in Copenhagen.

Comfort
Smoother asphalt on the cycle tracks.
Improved snow clearance and sweeping.
Effective bicycle parking (infrastructure, and collecting abandoned bicycles).
Services (air pumps, fountains, 'bicycle buddy' apps, weather reports, etc.).
Partnerships with workplaces and educational institutions regarding bicycle facilities and information. Better conditions for city employees (parking, changing rooms, bike repair, etc.).
Development of new products (valet parking for cyclists, surface treatment for cobblestones, etc.).

Lifestyle and image
Marketing relating to image, lifestyle, the advantages of cycling.
Campaigns aimed at target groups who have the potential to cycle more, including newcomers, the elderly and people who use the car for short trips.
A sense of ownership, for example campaigns like Your Bicycle City, Your Mother's Bicycle City.
Online – a one-stop bicycle portal.

Experiences
Integrating the feeling of wind and weather into cycle track design.
Communicating positive bicycle experiences (including ideas like Your Favourite Route, Your Favourite Short Cut).

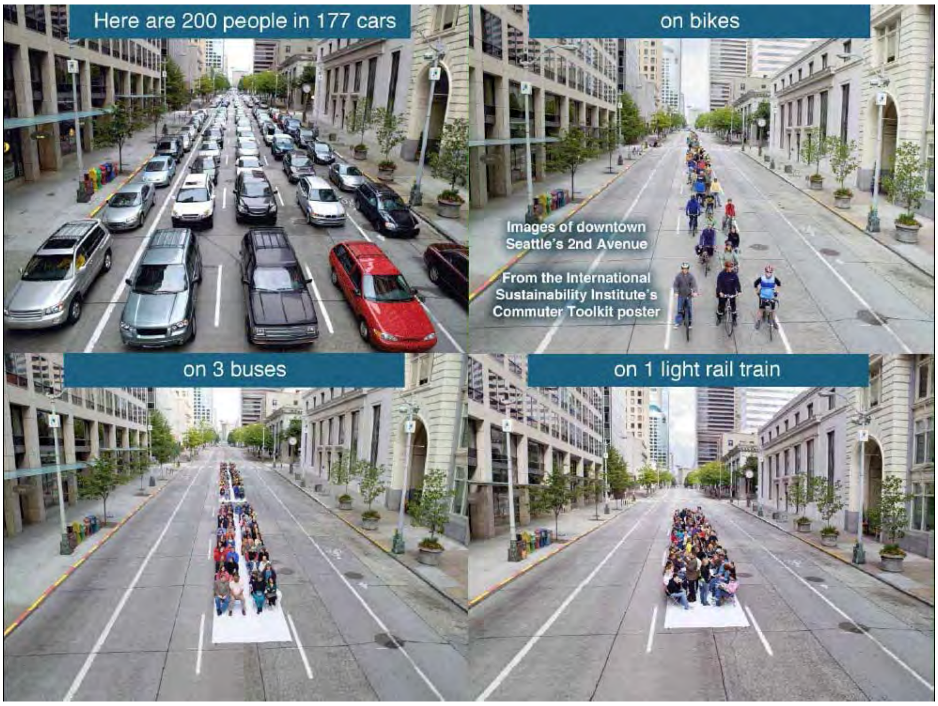
The rhythm of the street in Copenhagen: sharing the street space differently at distinct hours



Funding has been allocated in Copenhagen to ITS solutions for cyclists. Pilot projects with LED lights embedded in the asphalt, with alternating use of space like virtual bus stop islands (2012–2013). Source: City of Copenhagen.

Copenhagen aims to design its streets with pedestrians and cyclists in mind. The streets in 2025 are envisioned to handle rush hour, peak shopping hours, evening life and night activities. By using ITS (Intelligent Traffic System), the street is transformed from being static to being dynamic. LED lights in the asphalt signal which transport form has priority and when. Certain stretches, for example, can be made one-way for cars for some periods of the day, just as cycle tracks can be widened during the morning rush hour by taking over space from the sidewalk. The sidewalks can then be broadened during the middle of the day to accommodate more pedestrians and fewer cyclists. Letting the street follow the natural rhythm of the city and not vice versa, creates more vitality and a more pleasant urban space.

PROMOTE PUBLIC TRANSPORT



Source: International Sustainability Institute.
Above left are 200 people in 177 cars. They fill the street to the horizon. The other images are on bikes (upper right), buses (lower left), and on a streetcar (lower right). Low-occupancy vehicles are a tremendous waste of street space.

Public transport is the most efficient means of moving people over distances that are too long to walk and cycle. Individual motorized transport will never match high capacity transport for meeting increased demand. Future mobility services such as connected autonomous vehicles (CAV) should complement rather than compete with public transport, by making it easier to get to and from major transport hubs.

Public transport supports good health, because it tends to involve some active travel. It limits the community impact on the environment and frees up street space for people. It opens up opportunities and links communities. A neighbourhood potential development depends heavily on good public transport connectivity.

High-quality services should interweave seamlessly with other forms of active, efficient and sustainable travel.

To encourage more people to use public transport instead of cars, services must consistently be customer focused, accessible and affordable. The complementary modes of walking, cycling and public transport should interlink at transport hubs and on streets. Connectedness and continuity are key: a complete sidewalk system, secure cycling and pedestrian paths, and clear routes to safe and clean bus and subway stations increase public transport ridership.

Integrating the pedestrian realm with interlinked bus and subway services in London. Source: Mayor of London 2018.

Sustainable neighbourhoods integrate:
Close, comfortable and accessible public transport stops with inclusive features for children, the elderly, and people with disabilities

- Frequent and connected service
- Small-scale blocks with frequent street intersections
- Streets lined with a dense and diversified retail experience
- Tree-lined, shaded, and pleasant sidewalks
- A pedestrian network across parks with shortcuts through green courtyards within blocks

One barrier to utilizing urban rail is the last mile – the final journey from a person's location to the station. Integration should enable travellers to go easily to mass-public transport stations, using e-scooters, bicycles, or new forms of public transport such as shared electric vehicles fleets. Bike sharing fosters increased public-public transport usage in Beijing, Melbourne, New York City, and Washington, DC[52].

Inclusive design across the transport system should ensure it is convenient to all. Public transport operators must make walking and cycling environments accessible to older and disabled people, and provide lifts, level access and customer care and information at stops and stations so people do not have to resort to private transport.

PREPARE FOR SEAMLESS CONNECTED AUTONOMOUS MOBILITY

Connectivity, autonomy, sharing and electrification are already disrupting urban mobility. These four technologies, if implemented effectively, could unlock seamless mobility. In such a system, residents enjoy reliable and safe travel, facilitated by a range of techs, including robo-taxis, autonomous shuttles, intelligent traffic, advanced rail signalling, and predictive maintenance.

A seamless integrated transport system enabled by new technologies

Seamless mobility can be defined as a system in which the boundaries between private, shared, and public transport are blurred, and travellers have a variety of clean, cheap, and flexible ways to get from point A to point B[53]. It could be greener, more user-friendly, and more efficient than current options. The technology brings the capacity to make great progress in the following areas[54].

- **Safety.** With over 90% of road incidents assignable to human driver error, the potential to reduce danger is significant.
- **Convenience.** Fifty percent more point-to-point journeys.
- **Availability.** Accommodating up to 30% more traffic (passenger kilometres per year) with the same routes. In existing cities useless street width will be converted into green zones or reclaimed for real estate programmes.
- **Efficiency.** Cutting travel times by 10%.

[52] Yuanyuan Zhang and Yuming Zhang 2018.
[53] McKinsey and Bloomberg 2016.
[54] McKinsey Center for Future Mobility 2019.

- **Affordability.** Average cost per trip 25–30% less expensive.
- **Air quality.** 85% fewer emissions.
- **Creating public realm by diminishing the need for parking lots.** Around 15–30% of land in large cities is currently designated to parking spaces[55]. New mobility models could reduce the demand for parking, freeing up land for building new homes or green and open space. This will have associated benefits such as enhanced physical and mental health and will mitigate the higher temperatures and air pollution in urban areas[56].

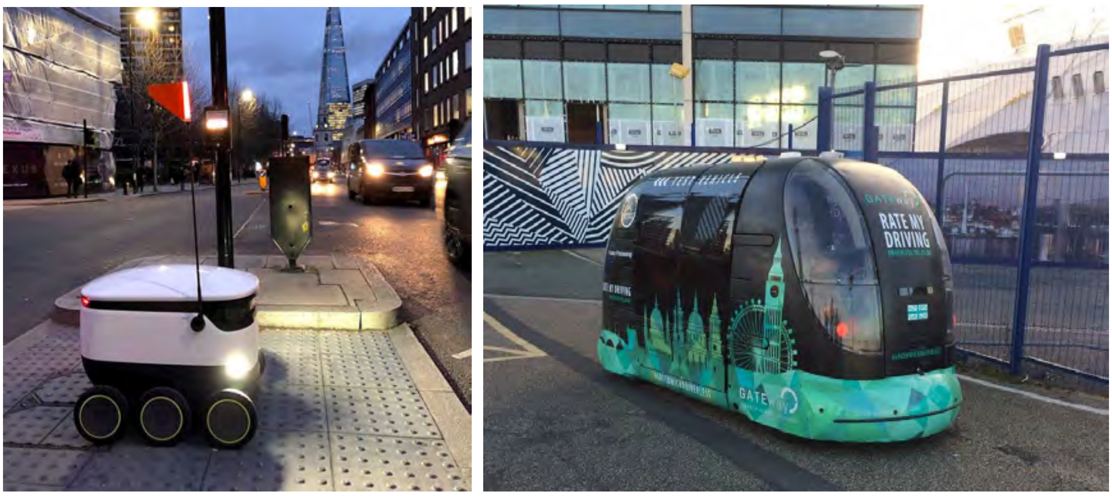
To realize seamless mobility, cities need tools that optimize supply and demand, and improve sustainability, as well as business models, innovations, and technologies.

With regulation and incentives, cities can steer the use of shared autonomous vehicles (AVs) while controlling the size and composition of the AV fleet. This will allow them to achieve specific goals, such as availability, efficiency, affordability, convenience and durability[57].

According to McKinsey simulations, with seamless mobility, private cars and robo-taxis could provide about 30% of passenger – kilometres in 2030, compared with 40% for private cars today. Residents could 'mix and match' rail public transport and low-cost, point-to-point travel in robo-taxis and autonomous shuttles. Rail would remain the backbone of the public transport system, delivering about 40% of urban passenger-kilometres.

A major technological disruption

Connected Autonomous Vehicles (CAVs) will be one of the most transformational and disruptive technologies ever introduced. US$100 billion has already been directed globally to CAVs development worldwide, based on the potential benefits of the associated safety, health, accessibility and economic opportunities. An autonomous vehicle can drive itself with little or no human input. There are five degrees of automation.

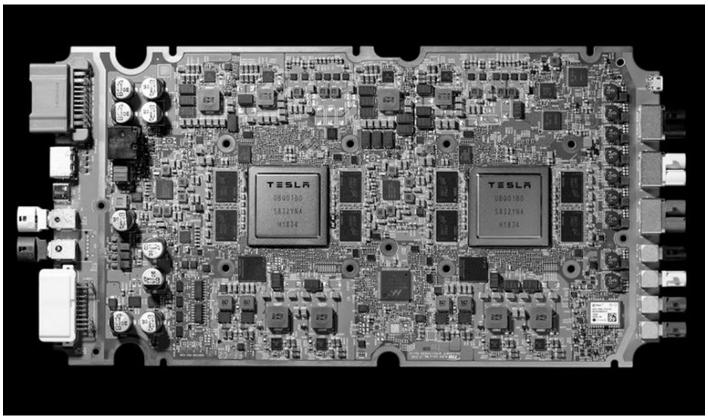


Left: Starship delivery robot at pedestrian crossing, Southwark. Source: London Assembly 2018.
Right: Autonomous vehicle trial run by the GATEway project in Greenwich. Source: London Assembly 2018.

[55] U.K. Department for Transport 2019.

[56] At the same time, AV technology could also exacerbate congestion, lead to suburban sprawl, increase GHGs, exacerbate inequalities and make communities less liveable. Which of these seemingly contradictory outcomes will materialize will depend on the public policies put in place. With so much at stake, we must prepare for this future.

[57] McKinsey Center for Future Mobility 2019.

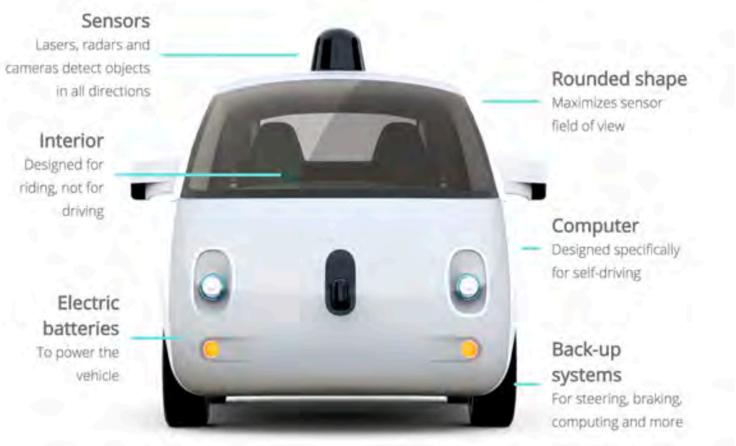


Central to the Tesla system is a 'full self-driving computer', or FSDC. This consists of two duplicate systems next to each other on one board for redundancy, and thus safety purposes.
Large-scale neural-network training and visual recognition are necessary for Level 4 and Level 5 autonomy. Sensors inside Tesla vehicles lean on a neural network that's trained by data collected by all Tesla vehicles. Tesla's self-driving software is storing images and learning at an exponential rate. In 2019, Tesla had 500,000 vehicles on the road. Each of these vehicles is equipped with eight cameras, ultrasonic sensors, and radar gathering data to help its neural network, so that the vehicle can recognize images, determine what objects are, and figure out what to do.

MONITORED DRIVING		
DRIVER ASSISTANCE	**1**	Vehicles can assist with some functions, but the driver handles all accelerating, braking, and monitoring the environment.
PARTIAL AUTOMATION	**2**	Vehicles can assist with steering and automation functions. The driver must always be ready to take control of the vehicle and is responsible for most safety-critical functions and monitoring.
NON-MONITORED DRIVING		
CONDITIONAL AUTOMATION	**3**	Vehicles monitor the environment using sensors. The driver's attention is still required, but they can disengage from safety critical functions like braking when conditions are secure.
HIGH AUTOMATION	**4**	The vehicle is capable of steering, braking, accelerating, monitoring the vehicle and roadway as well as responding events. Drivers choose to switch to this mode when conditions are safe.
FULL AUTOMATION	**5**	Vehicle controls all functions with no human attention or input required

There is a debate regarding which path the public transportation will take.

- **'Evolutionary' path: growing automation and connectivity of current vehicles** (e.g. autopilot features and GPS systems that already exist) towards fully autonomous vehicles.
- **'Revolutionary' path: fully autonomous vehicles like the one built by Google subsidiary Waymo, or by Tesla become increasingly mainstream.**



Google self-driving car

Public policy for sustainable AV deployment

Issues surrounding AV technology transcend many facets of society. They will have an impact not only on transport, but also on land use planning, economic well-being, health, liveability, environmental sustainability, as well as other areas. Without public policy that ensures that AVs are shared and electric, they may exacerbate car-related present problems. With well-conceived public policy, they can bring life, health, safety, beauty to our streets. Cities will need to regulate AVs if they are to be a boon and not a bane. Ways encompass

- owning the data.
- preserving public transport.
- prohibiting empty (circling) trips.
- setting speed limits.
- protecting traditional urbanism[58].

The potential benefits and costs of AVs hinge on whether the predominant model is shared use or single occupancy and 'zero-occupancy' vehicles private ownership. Shared use will result in fewer cars and less congestion. Private ownership may end up in more cars, more congestion, and diminution of other transportation modes. Vehicle miles travelled (VMT) may increase under any scenario, meaning that electrification of the AV fleet will be imperative to reduce greenhouse gas emissions[59].

The best outcome for our communities to incorporate autonomous vehicles is ***balanced autonomy*** – integration where AVs do not dominate humans, land use, and pedestrian environments. Core to achieving this is to leverage land use planning as a form of travel demand management that

- Decreases the amount of travel (sustainability).
- Lowers the impact of that travel (liveability).
- Ensures places and transport services are accessible without unduly harming vulnerable groups (equity).

The following policies could lower the number of vehicle miles travelled, and thus street capacity demand.

- **More vehicle sharing**, which can be accomplished through transportation demand management (TDM) policies and pricing incentives.
- **Slower, human scale vehicles**, that are guided to travel on appropriate streets and away from within neighbourhoods. This supports liveability and equity objectives.

[58] Speck 2017.

[59] Studies show that, if right policies are not put in place, there might be significant increases in vehicle travel. Without vehicle sharing, AV technology could increase overall vehicle travel by 15 to 20%, assuming a modest 50% reduction in the personal cost of travel (Fulton et al. 2017). Even in optimistic vehicle sharing scenarios, which could lead to a 90% drop in vehicles overall, AVs could still lead to a 10% increase in travel (Mekuria et al. 2017).

- **Shorter trip distances can be achieved with land-use planning.** Infill development should curtail the sprawl that often comes with reducing the personal cost of travel. Only this will realize sustainability objectives such as lower consumption of energy and land resources[60].

Based on an optimal scenario, the following **policy recommendations** might help achieve the best outcomes for a future with autonomous vehicles[61].

- All autonomous vehicles should be low emission releasers – electric or hybrid minimum. Fleets of electric, connected, shared, autonomous vehicles could balance building energy production and use in a smart grid powered by renewables.
- Pedestrians, cyclists and vulnerable road users should be prioritized by diminished auto right-of-way
    - routing traffic to appropriate streets (commercial over residential).
    - limiting speed of autonomous vehicles to 20 kilometres per hour to improve safety and liveability.
- Integrated mixed-use planning achieving better jobs/housing balance, and growth management practices should be mandatory in cities allowing the use of autonomous vehicles to reduce the risk of urban sprawl. There is concern that AVs may encourage sprawl, but they also offer potential hopes for 'sprawl repair'. Neighbourhoods may become more efficient for public transport through integration of land use and mobility hubs. Those would provide seamless transfer across many options and partnership models. As mobility shifts, new value capture opportunities will emerge analogous to those of transit-oriented development (TOD).
- Autonomous vehicles require to be implemented on a leased or shared-ownership basis to encourage carpooling and to incentivize longevity of product life.
- Pedestrian and cycling based infrastructure needs are to be given similar or equal investment in comparison to autonomous vehicle infrastructure and street redesign.

Key Principles in the UK for facilitating innovation in urban mobility for freight, passengers and services[62]

1. New transport modes and new mobility services must be safe and secure by design.
2. The benefits of innovation in mobility must be available to all neighbourhoods and all segments of society.
3. Walking, cycling and active travel must remain the best options for short urban journeys.
4. Mass transit must remain fundamental to an efficient transport system.
5. New mobility services must lead the transition to zero emissions.
6. Mobility innovation must help to reduce congestion through more efficient use of limited road space, for example through sharing rides, increasing occupancy or consolidating freight.
7. The marketplace for mobility must be open to stimulate innovation and give the best deal to consumers.
8. New mobility services must be designed to operate as part of an integrated transport system combining public, private and multiple modes for transport users.
9. Data from new mobility services must be shared where appropriate to improve choice and the operation of the transport system.

[60] Appleyard and Riggs 2017.

[61] Appleyard and Riggs 2017.

[62] U.K. Department for Transport 2019.

Two strategic paths for integrating future mobility systems

Digitalization is one of the main drivers for upgrading the mobility system to a completely new level where mobility will become 'a truly connected system'. Means of transportation that remain unlinked today must develop into mobility ecosystems. Customers will

- Be able to get intuitive and continuous information about a comprehensive travel chain.
- Get easy access to transportation (e.g. through mobility platforms).
- Enjoy easy and smooth methods of payment.

The two strategic paths are

- **'Rethink the system'** for autonomous vehicles.
- **'Network the system,'** i.e. work towards seamless mobility, with the customer at the centre.

They both lead to 'mobility-as-a-Service'

- **Intermodal.**
- **Personalized.**
- **convenient.**
- **connected.**

The progress towards integrated traffic and network management will be accelerated. The ability to interface systems will address the movements of both people and goods across modes. The increased linkages between people, vehicles and goods will boost the overall system performance**.** Prioritizing system-level connectivity and coordination among vehicles over individual vehicle automation could result in significant gains in energy efficiency[63]. The successful integration of shared and automated mobility services with public transport, walking and cycling could reduce energy consumption and carbon emissions. Feeder services provided by shared and automated vehicles could encourage the use of high-capacity public transport. In densely populated cities with good public transport systems, digital transformation could help to move away from the traditional paradigm of vehicle ownership toward shared mobility.

Recommendations for future mobility city planning

The urban form that may ultimately emerge is compelling: a city with almost no on-street parking, housing free of garage costs, abundant pedestrian zones, ubiquitous bike lanes, and no surface parking lots. What's more, each step along the way will improve our existing communities.

Cities need to invest in smart systems across four layers

- **Infrastructure**

The base layer of an urban mobility system is made up of its physical infrastructure (such as roads, rails, stations and parking lots) and the energy that powers it.

  - **Redesign** streets for smart traffic.
  - **Connect** smart streets and smart energy.
  - **Equip** streets with sensors for traffic management and predictive maintenance, dynamic lanes and traffic lights.
  - **Provide** storage and maintenance facilities for fleets of shared electric vehicles.
  - **Provide** rapid charging infrastructure.
  - **Equip** dedicated lanes with vehicle-to-infrastructure communications and IT systems.

Dynamic lanes

A central computer maximizes the flow of traffic. It can configure streets by time of day. A street may function as a four-lane street during peak periods and as a two-lane street during off-peak hours. Computers can program speeds. Through quiet neighbourhood streets, they can set the speed at 20 to 24 km/h, for example. Even with modest increases in automation, there is the potential to influence the driver/vehicle behaviour in real time to travel at slower speeds, and be routed to avoid sensitive areas.

[63] Wadud et al. 2016.

Smart Grids and Renewable Energy Infrastructure

The different energy profile associated with seamless mobility will also affect energy infrastructure, while offering innovative integration opportunities. Charging will become a new planning need. In addition, when electric vehicles start hit the road in large proportions, utilities will face climbing peak loads, which could increase as much as 30% in residential hot spots for electric vehicles. One way for utilities to adapt could be to encourage consumers to change their charging behaviour. By raising the number of people who charge their vehicles during periods of excess local production and low local demand, utilities could minimize the impact on the network and facilitate the stability of renewables within the grid. They could also work with EV owners to provide valuable system balancing (frequency response) services.

- **Rolling stock**
  - Buy rolling stock for mobility as a service distributed in shared systems through connectivity platforms.
  - Identify optimal locations to deploy a diversified fleet of autonomous and connected vehicles – need to create a transport model and an O-D matrix (origins/destinations).

- **Digital and analytics**
  - Smart ticketing and payment.
  - Create interactive maps with routes and times.
  - Match vehicles and routing.
  - Track and price congestion.

Invest in technologies such as
- Traffic-flow management
- Real-time mobility information
- Vehicle routing
- Digital maps
- Vehicle tracking

- **User interfaces**

The final layer is the interaction with the passengers themselves, via navigation apps and associated mobile payment platforms.
  - Develop navigation apps.
  - Develop integrated payment through smartphones.

These interfaces have already changed the way people utilize infrastructure, rolling stock and data on the public transport system. They make it easier for them to plan journeys mixing different types of mobility. They help them choose the routes or move trips from passenger cars to shared options.

Recommendations for future mobility street design[64]

Reduction in vehicles from AV adoption allows optimizing streets for pedestrians. Source: Snyder 2018.

Seamless connectivity and future autonomous vehicles can make the most of the upcoming streets and eliminate the need for large ones. With the right design, shared and electric automation will affect positively the sensory quality and feel of streets.

[64] This section draws on Snyder 2018.

In the Connected Automated Vehicle future, people will

- Use fewer cars (through greater sharing).
- Travel shorter distances (through better land use planning).
- Travel at slower speeds (through digital monitoring).

This will make streets highly liveable. Future mobility should be integrated from start in master plans in at least the following ways.

- **Street cross-sections and public space: Designing with a boulevard typology**

Autonomous vehicles need less road space than a manually driven vehicle. Their ability to communicate with the transportation network as well as each other allows them to operate

- with a smaller following distance.
- in narrower lanes.

As a result, **roads will require less pavement width.** The space gained may be used to.

- Narrow streets width.
- Enlarge the pedestrian realm within streets.
- Create rows of closely spaced trees providing a continuous shading canopy and moderating the hot climate and harsh light.

Space might also be transferred to the adjacent property owners. This will create higher real estate value. Streets will have a better feeling of enclosure with a shape factor[65] closer to the proportions between 1 and 2 observed in most European cities.

Freeing up a significant amount of space can be done by.

- ***Diminishing the number of travel lanes.*** AVs will safely space themselves much closer together than human-driven vehicles and can even 'connect' and form platoons[66]. Moreover, the shift towards Transportation as a Service and shared mobility options will decrease the number of vehicles on streets. The increase in capacity of travel lanes due to the automation and sharing of traffic opens the possibility to reduce the number of travel lanes for vehicles and use the space for extending green and pedestrian areas.
- ***Lowering the amount of on-street parking.*** On average, our cars are parked 95% of the time, so they are only in use 5% of the time. As Transportation as a Service will more and more replace car ownership, this will reduce parking, freeing up this space for other public utilizations[67]. Self-parking cars could save approximately 60% in parking area[68].
- ***Minimizing lane widths.*** As AVs will be better able to stay in lanes, those could be reduced to 2.4 m or 2.7 m in width. These lanes are also pedestrian-friendly, as they are easier to cross.
- ***Bidirectional lanes.*** Some residential streets and those with low traffic volumes may exploit lanes that enable cars to travel in either direction as needed. One key feature of AVs will be vehicle-to-vehicle (V2V) communication so that vehicles will talk to each other and coordinate movements[69].

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[65] The shape factor is the height of adjacent buildings divided by street width from façade to façade.

[66] Typically, transportation planners use 20,000 vehicles per day (Average daily traffic – ADT) as a threshold for taking a four-lane street down to two lanes, usually with a centre-turn lane. At this volume, two lanes provide sufficient capacity. Four lanes provide enough capacity for up to around 40,000 ADT. This is approximately the threshold for reducing six-lane streets to four. Since AVs will safely space themselves much closer together than human driven vehicles, they won't likely need the same number of lanes that human-driven vehicles do. The threshold for taking four-lane streets down to two-lane streets without impacting capacity may jump to 35,000 or 40,000 ADT. Similarly, the threshold for taking six-lane streets down to four lanes, may rise to 50,000 or 60,000 ADT.

[67] Greater vehicle sharing potentially frees up valuable land for redevelopment and the provision of affordable housing. Pro Forma analyses from San Diego's London Moeder advisors estimate the cost of construction can be reduced by 20-25% if structural parking is eliminated (Moeder, n.d.).

[68] Audi USA. (n.d.). /newsroom/news/press-releases/2015/11/audi-brings-automated-parking-to-the-boston-area

[69] Today we use bi-directional centre-turn lanes that could be used as bi-directional travel lanes.

All of these provide the opportunity to free a significant amount of street space for repurposing to higher and better uses; and on smaller or residential streets, to bring widths down to 5–6 metres. Boulevard design should replace arterials and collectors in business-as-usual master plans. They can be improved with

- Protected or improved bike lanes.
- Wider sidewalks.
- Street furniture.
- Public art.
- Fountains.
- Streetscape and landscape.
- Outdoor dining.
- Jogging paths.
- Playgrounds.

- **Traffic management**

Traffic signals, signs, and street markings will need to change to accommodate autonomous vehicles, especially where they can help reduce potential conflicts between vehicular traffic and nonmotorized road users, such as pedestrians. Optimizing a street for AVs will require the installation of various sensor types and communications technology to allow vehicles to travel more efficiently.

- **Digital and electric Infrastructure**

Vehicle-to-infrastructure (V2I) enables vehicles to exchange information with traffic signals, transmitters, and central computers. This communication will make AV travel safer. It opens up other opportunities such as

- prioritizing certain vehicles.
- maximizing flows.
- reconfiguring street uses according to times of the day.
- limiting speeds.

Recharging stations at strategic locations.

- **Kerb management**

As significant numbers of people shift from automobile ownership to Mobility as a Service, the demand for pickup and drop-off along streets will increase. The management of sidewalks will present new challenges.

DECARBONIZE NEIGHBOURHOOD ENERGY

Nearly everything produced or consumed necessitates energy. Its worldwide demand is expected to double by 2050. Limiting global warming to 1.5 °C, the goal set by the Paris Agreement, requires a rapid deployment of low-carbon technologies. Decarbonizing the urban energy sector has a high carbon mitigation potential. Energy production is, for instance, tasked to provide about three quarters of the emission reductions needed to reach Copenhagen's carbon neutrality target by 2025[70].Three key trends are paving the way.

- **The rapid deployment and lower costs of clean energy technologies.**
  In 2016, the growth of solar photovoltaic capacity was greater than for any other form of generation. Since 2010, its cost has decreased by 70%, those of wind energy by 25% and those of batteries by 40%[71].

- **The increasing electrification of energy.**
  In 2016, world consumers' expense on electricity almost reached parity with spending on petroleum products[72].

- **The rapid deployment of digital technologies across the energy sector**[73]**.** They help incorporate variable renewable energies. They enable networks to match demand with the sun and wind[74].

[70] City of Copenhagen 2012.
[71] IEA-2017a.
[72] IEA-2017a.
[73] IEA 2017b.
[74] In the European Union alone, an increase in storage and demand response enabled by digital technologies

Cities need to set clear goals for decarbonization. They can aggregate demand for renewable energy and promote energy efficiency.

The neighbourhood is the good scale for optimizing energy demand and renewable integration. An energy and resource sharing perspective should guide planning the mix of uses. It can be balanced to reduce peaks and foster synergies and exchanges between industry, housing, office and commercial buildings. Each function in a neighbourhood has its own model of energy intake. Adding activities to the right place facilitates heat and cold exchanges between buildings[75]. This may result in a significant reduction in energy consumption for the building stock. This smart form of energy interaction requires organizational innovations.
The integrated strategy at neighbourhood level starts by lowering demand for resources and energy to accelerate circular economy processes and renewable energy supply.

- **Lower transportation energy demand and reduce the total energy demand for building operation to 40–50 kWh/m²/y**
  - Integrate public transportation provision with land use intensification
  - Design well connected, fine grain, mixed-use, pedestrian-friendly neighbourhoods with ample provision of green public space
  - Design a climate responsive urban fabric layout
  - Design buildings for energy efficiency
  - Manage the demand
- **Close the loops**
  - The energy generated from local waste streams (about 30 kWh/m²/year for residential areas[76]) is almost enough to meet reduced demand. The distribution of waste heat can be undertaken by district heating.
  - It takes then a small amount of wind, solar or geothermal energy to reach a 100% renewable energy supply.
  - An integrated hybrid combination of waste-to-energy systems, wind and solar power optimizes the size and cost of each system. It balances the use and timing of each renewable energy source.

A mix of its best natural and engineered capital powers the neighbourhood. It becomes its own micro-utility.
Among the most energy-efficient communities, are Kronsberg[77] and Vauban with their passive buildings. They demonstrate that heating energy demand objectives of 15–25 kWh/m²/y in a cold climate[78] are workable. When this is combined with an electric demand target of 20–25 kWh/m²/y, a total consumption about 40–50 kWh/m²/y[79] is cost-effective. This level of energy performance makes it feasible to supply most, if not all, energy from local renewables. As demonstrated by Vauban, which has a very low energy demand, the pairing of solar photovoltaics and a waste-to-energy cogeneration plant comes to 85% renewable. The goal for total energy intake was 105 kWh/m²/y, and the reported consumption was 75 kWh/m²/y. The energy sources were 85% renewable (4% solar and 81% waste).

could avoid around 30 million tons (Mt) of carbon dioxide emissions in 2040 (IEA 2017b).
[75] Tillie et al. 2009.
[76] As suggested by the case study of Hammarby Sjöstad (Fraker 2013).
[77] 15 kWh/m²/y for its passive houses
[78] 6,000 heating degree days
[79] Including cooking and hot water

Renewable energy architectural integration in BedZED. Photo: ©Françoise Labbé.

Action at neighbourhood level involves

CONSERVE ENERGY AND MINIMIZE THE DEMAND
INTEGRATE ENERGY SYSTEMS AT NEIGHBOURHOOD LEVEL
ELECTRIFY THE NEIGHBOURHOOD ENERGY WITH RENEWABLES
INTERCONNECT WITH SMART GRIDS

CASE STUDY: BEDDINGTON ZERO ENERGY DEVELOPMENT INTEGRATED APPROACH IN THE UK[80]

Beddington Zero (fossil) Energy Development or BedZED, is the UK's largest eco- village. The architect Bill Dunster designed the development. Together BedZED shows how green living is a real, attractive and affordable option. Energy efficiency, renewable energy and water conservation are successfully integrated with a car club and local organic food deliveries.

[80] This box draws on BioRegional Development Group 2002.

BedZED targets

—Environmental: low energy and renewable fuel, including biomass combined heat and power (CHP) and photovoltaics (PV), zero net carbon emissions, integrated water conservation strategies, reclaimed materials, Green Travel Plan, and biodiversity measures.
—Social: mixed tenure, two-thirds affordable or social housing, lower fuel and water costs, community space, sports pitch, child-care facilities, 'village square', private gardens for most units.
—Economy: Locally sourced materials, workspace for local employment and enterprise, locally available renewable energy resources.

BedZED. Photo: ©Françoise Labbé.

Environmental

BedZED achieves a 50% reduction in transport energy consumption through a combination of public transport, using car clubs, walking and cycling. One method of reducing car ownership and use successfully operated at BedZED is the car club, ZEDcars. The service allows residents to hire a car by the hour when they need one, thereby providing mobility insurance without needing to own a vehicle. To reduce the need to make regular car journeys to the supermarket, the development encourages the use of home delivery services from supermarket chains and local organic food suppliers. Residents have access to an Internet point and secure storage facilities for unattended deliveries. Choosing local and organic food dramatically reduces the typical household's eco-footprint due to food consumption. A Biodiversity Plan was developed to maximize spaces for wildlife in the urban environment.

BedZED. Photo: ©Françoise Labbé.

Existing features of the site have been retained or enhanced to increase biodiversity and natural amenity value. The boundary line of mature horse chestnut trees has been retained. The existing ditches have been developed into water features. Private gardens are provided to 71 of the 82 units. These are an average size of 16m2 and are predominantly roof gardens located on top of workspaces.

BedZED is Britain's first urban carbon-neutral development. It achieves high standards in environmental performance through the implementation of three strategies:

—Energy-efficient design of the buildings – reducing heat losses and utilizing solar gain to the point where it is feasible to eliminate conventional heating systems
—Energy efficient and hot water saving appliances to reduce demand
—Use of renewable energy sources – wood-fuelled CHP and PV power integrated into the sunspace roofs. The development will become a net exporter of renewable energy

Social

In addition to having residential, lifework and commercial units, BedZED provides community facilities. Units accommodate a child-care facility and a doctor's surgery. A sports pitch with a clubhouse provides communal space. A multipurpose space currently houses the BedZED exhibition. Community events regularly use it. A village square with native trees and seating lies at the heart of the development, forming part of the pedestrian route through the site.

BedZED. Photo: ©Françoise Labbé.

Lessons learned

The BedZED sustainability principles have been translated into practical strategies to reduce environmental impacts and create a highly liveable community. This project highlights the importance of early strategic thinking and commitment to providing integrated solutions to sustainable community development. Many of the lessons learned and techniques refined at BedZED are transferable to other projects, whether involving new build, refurbishment or successful community management through ongoing energy and water efficiency and waste reduction. As a model, BedZED can be tailored for different uses and locations, but the core principles of local sourcing, integrated mixed-use development linked with solar design, renewable power, and maximizing the community, economic and amenity values, are widely applicable.

CONSERVE ENERGY AND MINIMIZE THE DEMAND

Demand should drive energy planning. Designing the neighbourhood fabric and the buildings according to bioclimatic and passive principles should first reduce energy needs. Value engineering should then guide the choice of energy-efficient appliances.

Efficient urban forms

Different climates require distinct urban fabric layouts, building shapes and orientations. Compact forms that are effective in cold climates are inefficient in tropical climates[81] where thin structures and ample provision of air funnels across the urban fabric and through the buildings themselves are necessary. High levels of insulation may have adverse effects in tropical weathers where passive house concepts may not be optimal solutions and increase instead the energy loads. In cold climates, there is a significant difference between comfortable indoor and outdoor temperatures. Building envelopes and airtightness therefore are important to prevent heat loss. It is the opposite in tropical climates where creating 'breathing' edifices for natural ventilation is the most energy-efficient strategy.

An integrated approach of building energy efficiency

Buildings and construction together account for 36% of final worldwide energy use and an estimated one third of global greenhouse gas (GHG) emissions[82]. Furthermore, the construction sector is experiencing unprecedented growth, as between 2012 and 2025, one billion buildings will be needed worldwide[83]. This provides a critical window of opportunity to address buildings to avoid lock-in over the next forty years. If business-as-usual practices continue, greenhouse gas emissions from buildings will more than double in twenty years[84]. Moreover, since building stocks tend to be renewed only every thirty to fifty years, avoiding errors will prevent further infrastructure lock-in and potential costs for decades.

Efficiency upgrades, including building envelope measures, could represent nearly 2,400 exajoule (EJ) in cumulative energy offsets to 2060 – more than all the final energy consumed by the global buildings sector over the last twenty years[85]. These offsets are essential to improve the services and comfort in buildings, using less energy at net-zero net emissions.

In an integrated process, all the building subsystems are evaluated for the local climate. Their interrelationships are optimized. The goal is to gain value at every step (value engineering). Choices about all systems, encompassing equipment selection, sizing, and placement, are made within the design process, not as afterthoughts in the field. Analytical tools and the input of all pertinent disciplines help decision-making. Rather than a traditional linear process, the integrated process involves looping in ongoing input from relevant sources[86]. Integrated approaches explore the potential of passive strategies and life cycle costing and may include first expense transfers from conventional heating, ventilating, and air conditioning (HVAC) systems to the building envelope.

[81] Salat 2018.
[82] UNEP and International Energy Agency 2017. Moreover, 82% of final energy consumption in buildings was supplied by fossil fuels in 2015 (including primary energy input for power generation; traditional use of biomass excluded).
[83] Between 2012 and 2025, 1 billion buildings will be needed worldwide, of which 75% will be residential and 25% commercial (McKinsey 2012). By 2060, buildings sector floor area will double, adding more than 230 billion m^2 to the world in new buildings construction. Those additions are equivalent to building the current floor area of Japan every single year from now until 2060 (UN Environment and International Energy Agency 2017).
[84] UNEP 2009.
[85] IEA 2013.
[86] US Department of Energy 2011.

Check list of energy efficiency measures for buildings

Energy efficiency measures for buildings complete efforts made in designing bioclimatic urban fabrics (see chapter Designing with nature). They include

–Climate-sensitive architecture employing passive solar energy, natural ventilation and daylighting and seasonal fixed and mobile shading devices. Climate responsive architecture is linked to the performance of the urban fabric as the urban form determines the potential of buildings for natural lighting, natural ventilation, solar gains or mutual shading. Strategies, including at building scale are explained in the chapter Designing with nature.
–Improving insulation values, high performance windows and low air infiltration resulting in good quality construction.
–Increased efficiency of lighting and appliances.
–Better heating, ventilation, and air conditioning management and controls.
–Installation of 'smart metres' to give residents real-time feedback on performance.

Check list of passive buildings key design features
–The orientation should be aligned from west to east as far as possible.
–The window-to-wall ratio should be less than 20% in cold climates.
–Roofs should be constructed with thermal insulation.
–Light-coloured and reflective coatings should be applied on roofs and façades.
–External shading should be installed above all windows, exterior doors and vents.
–Interiors should have ceiling fans, before any air conditioners.
–Vegetation should shade the building and supply evaporative cooling.

Adapting buildings to the climatic environment minimizes operational energy input while achieving the comfort level of a conventional building. Two principles – active and passive design – are at work.

- ***Passive design*** exploits many design techniques to diminish the energy demand for heating, cooling and lightning.
    - Passive lighting employs natural light and can be combined with low-energy active systems to filter or complement light from the sun.
    - Passive cooling uses wind flows to cool the building. Hybrid systems with passive and active cooling can reduce cooling loads up to 60% in tropical climates.
- ***Active design*** captures sun energy by mechanical or electrical systems such as solar collectors and photovoltaic panels.

An integrated approach comprises

- Minimize building loads through passive strategies.
- Design energy efficient building systems
- Optimize controls.

Minimize building loads through passive strategies

In cold climates, passive solar design[87] should always come before other sources of energy. Sunlight is free, without carbon emissions. With legislation requiring increasingly higher insulation standards, passive solar design can provide so much energy that buildings need only minimal additional space heating. Planning streets within 30 degrees of east-west orientation forms plots appropriate for passive solar architecture. Heat gains occur on front and rear elevations. North-south oriented streets are more suitable for isolated structures or where floor height changes, allowing solar panels to access south-facing walls[88].

[87] The amount of heat gained from sunlight is calculated in degree-days over the heating period.

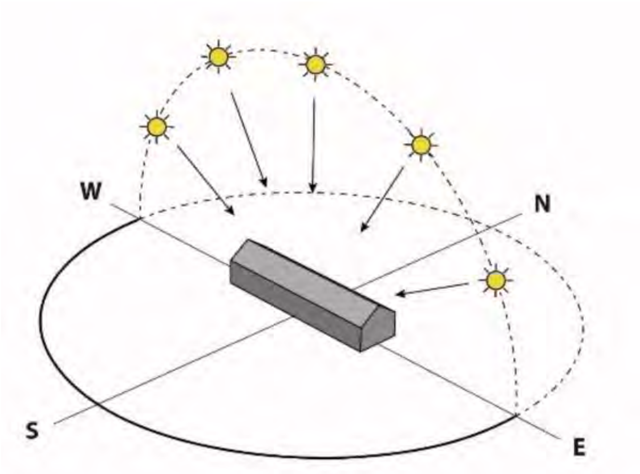
[88] English Partnerships and Housing Corporation 2007.

Traditional edifices in hot climates often achieve comfortable conditions without electricity. Long roof overhangs, exterior shading elements and green courtyards provide shade to buildings and diminish solar heat gains. The following passive design features reduce the energy demand for cooling[89].

- **Ventilation**
  A survey of office buildings in China shows that the use of natural ventilation can reduce the number of air conditioning hours needed by as much as 40%, while achieving the same indoor comfort level[90].
- **Landscape and vegetation**
  In residential areas, well-designed landscapes could save 25% of the energy used for cooling[91].

The landscaping should take advantage of the site environment, such as surrounding vegetation, bodies of water and the proximity of other structures, which may shade and cool the roof and façades of the new building. To reduce the urban heat island effect, green roofs, broad-leaved trees and bushes provide shade but do not impede air circulation.[92]

Orientation and Shape[93]



Orientation according to the sun. Source: PEEB 2020.

- **Orientation:** A building should be oriented from east to west along the main path of the sun, exposing only smaller façades to high solar radiation at low angles.
- **Shape:** In humid climates, larger distances between buildings permit better air circulation. In arid climates, compact buildings that are close together expose less façade to the sun and provide shade.
- **Openings:** Most openings (doors, windows, vents) should face north or south to reduce sun exposure. The window positions should enable optimal use of daylight, but with a small surface to prevent solar radiation inside. Horizontal glazing should be avoided.
- The **window-to-wall ratio** should be low to minimize internal heat gains while allowing for sufficient natural interior lighting. In hot climates, the window area must not exceed 20% of the total wall area.

Design energy efficient building systems

Recommended measures are

- Improving insulation.
- Smart and energy-efficient appliances.
- Waste-heat recovery systems.
- Solar thermal installations.
- Improved lighting technologies and greater use of daylight.
- Green roofs to enhance insulation.

Building Materials[94]

Buildings built with massive materials can store heat on a hot day, cool the air and release heat to warm the air at night. Conversely, constructions with low heat capacity exaggerate extreme temperatures.

[89] Gruner and Zinecker 2020.
[90] Fraunhofer Institute for Solar Energy Systems ISE 2017.
[91] IEA. 2018.
[92] Adapted from Gruner and Zinecker 2020.
[93] Adapted from Gruner and Zinecker 2020.
[94] Adapted from Gruner and Zinecker 2020.

- In **dry climate zones**, dense materials such as stone and brick reduce thermal fluctuations. Traditional buildings with thick earthen or stone walls rarely need to be cooled artificially. Those using lighter materials need thermal insulation.
- In **humid climate zones** with open building layout, lighter materials, such as wood (only where sufficiently available, preventing deforestation) and composite materials may be used.
- **Use materials with low embodied energy. Avoid excessive use of steel, glass and aluminium.** The term embodied energy or embodied carbon refers to the sum impact of all greenhouse gas emissions attributed to a material during its life cycle. This cycle encompasses extraction, manufacturing, construction, maintenance, and disposal. For example, reinforced concrete is a material with extremely high embodied energy[95]. Other construction materials, such as ceramic, brick, and plastic, similarly require large amounts of energy to be manufactured since the minerals used in them must be extracted and treated in energy-intensive processes. Understanding the amount of energy or carbon incorporated in building's materials is essential to creating more eco-conscious projects. A 'sustainable material' in one place may have a high energy load in another due to local availability and the type of transport involved. A standardized method of quantifying the environmental impact of buildings, from the extraction of materials and the manufacture of products to the end of their useful life and disposal, is the Life Cycle Assessment (LCA)[96]. Using a quantitative methodology, numerical results are obtained that reflect the impact categories and provide comparisons between similar products

Building envelope

Building envelope design (roof, exterior walls, windows and doors framing the enclosed space of a building), materials and construction have a large influence on heating and cooling loads. For the existing building stock, a full retrofit includes cooler roofs (which also decrease ambient temperatures in surrounding areas), improved wall insulation, better airtightness, and high-efficiency windows[97]. Increasing building insulation is the most effective strategy in cold climates. Research suggests that building insulation can diminish heating energy by 60% to 70%. Insulating a building with a high initial heat energy demand will result in a greater absolute energy savings[98]. High-performance thermal building envelopes (foundations, external walls, roofs and external doors) can reduce the cooling demand by 30% to 50%[99].

Building Envelope recommendations for hot climates are[100]

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95 When manufacturing the cement, large amounts of CO_2 are released in the calcination stage, where limestone is transformed into calcium oxide (quicklime), as well as in the burning of fossil fuels in furnaces. If we add these issues to the exploitation of sand and stone, to the use of iron for the rebar, to its transport to the construction site to be added to the mix, we can understand the impact of each decision of a project on the environment.

96 Using a quantitative methodology, numerical results are obtained that reflect the impact categories and provide comparisons between similar products

97 Globally, high-performance buildings construction and deep energy renovations of existing building envelopes represent a savings potential more than all the final energy consumed by the G20 countries in 2015, or around 330 EJ in cumulative energy savings to 2060 (UN Environment and International Energy Agency 2017). Rapid progress is needed to double the average annual improvement in building envelope performance (in kWh / m^2) from about 0.75% to over1.5 % per year. This would require considerable effort (including appropriate financing mechanisms) to ensure that markets adopt best practices and high-performance envelope technology solutions, particularly in fast-growing emerging economies, where new construction risks locking in less-than-optimal investments.

98 LSE Cities and EIFER 2014. Insulating walls should result in greater absolute energy saving if the initial through-wall energy losses (and thus heat energy demand) are high. Modelling results show that insulating a building which has higher initial heat energy demands results in a greater absolute reduction. The Parisian compact urban block has a heat energy demand of 97 kWh with a wall U-value of 2, reducing to 37 kWh when the U-value is reduced to 0.5 - a net energy saving of 60 kWh. However, Berlin detached housing shows a heat energy demand of 393 kWh at the high U-value of 2, reducing to 118 kWh at the low U-value of 0.5 - a much greater net saving of 275 kWh (LSE Cities and EIFER 2014).

99 IPCC 2014; Fraunhofer Institute for Solar Energy Systems ISE 2017

100 Adapted from Gruner and Zinecker 2020.

- **Walls**
  In dry climates, the walls are massive to keep out the heat during the day and release the slowly absorbed heat at night. In humid climates, the walls are light with many openings and vents for ventilation.
- **Roofs**
  In dry climates, roofs are massive or insulated. In humid climates, roofs are light and insulated. High-quality white roofs can reflect 80% of the sun's energy compared to black roofs that reflect only 5% to 10%[101].
- **Shading**
  Roof overhangs and exterior shading minimize solar radiation on façades and windows.
- **Coatings**
  Bright and reflective coatings on roofs and façades reflect solar radiation and prevent it from entering the interior. Vegetation can protect façades.
- **Windows**
  Low-emissivity glass reflects infrared solar radiation without affecting the entry of visible light and reduces cooling demand by at least 20% compared to conventional glass[102]. In dry climates, high-performance windows should be used with double glazing and solar film if no external shading is possible, optionally, with natural ventilation during night-time. In humid climates, louvre windows should be used with insect screens for natural ventilation. Optionally, high-performance windows can be effective in very hot and humid climates.

Appliances

The second step to decrease energy consumption is employing energy efficient appliances. They can result in an overall saving of 75% energy per household[103]. In warm or temperate climates, using rooftop space for solar water heating can be a relatively low-tech, low-cost solution for diminishing building emissions. Lighting accounts for 10 to 20% of energy consumption in buildings, with a slightly larger share in commercial structures than residential ones[104]. Switching to Light Emitting Diodes (LED) that last longer and produce more light per watt can reduce electricity demand for lighting by 30% contrasted with fluorescent lights and by 80% compared with incandescent light bulbs[105]. Instead of mechanical cooling, the use of ceiling fans should come first as they consume very little energy but significantly increase thermal comfort when it is hot. A ceiling fan provides a thermal sensation equivalent to lowering the indoor temperature by at least 2° C.

Optimize controls

Smart controls can complement human shift to sustainable practices and could save up to 230 EJ cumulatively to 2040, roughly twice the energy consumed by the entire buildings sector in 2017[106]. Smart thermostats can anticipate occupant behaviour (based on past experience) and employ real-time weather forecasts to predict heating and cooling requirements. Intelligent lighting can supply light when and where it is needed. LEDs can include sensors linked to other systems to customize heating and cooling services. These sensors and user controls can improve interaction between humans and edifices, while enhancing thermal comfort and providing greater convenience to building occupants. These savings would also reduce the carbon intensity of the electricity sector by better managing the supply and demand of energy on the grid.

Demand management

Smart energy management comprises three steps

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[101] IEA 2018.
[102] IEA 2019
[103] UN Habitat 2012 b.
[104] Lighting Efficiency: Climate Tech Book, Pew Center on Global Climate Change, April 2011, c2es.org.
[105] C40 and McKinsey 2017.
[106] UNEP and International Energy Agency 2017. International Energy Agency analysis (IEA 2017b) shows that digital transformation in the building sector could reduce energy consumption and associated emissions by around 10% by using real-time data to improve operational efficiency.

- Ensure that energy is consumed when and where it is needed.
  - Improve the responsiveness of energy services – e.g. by using sensors).
  - Predict occupant behaviour – for instance, with learning algorithms that automatically program heating and cooling services.

- Enable demand response in reaction to real-time energy prices or other conditions specified by the user.
  - diminish peak loads – for instance, adjust temperature settings to reduce demand for energy.
  - Store energy – for example, in thermal smart grids.

- Predict, measure and monitor the real-time energy performance of buildings. This allows consumers, building managers, network operators and other stakeholders to identify.
  - where and when maintenance is needed.
  - when investments are not achieving as expected.
  - where energy savings can be obtained.

CASE STUDY: ENERGY-EFFICIENT DESIGN OF BEDZED BUILDINGS, UK[107]

BedZED. Photo: ©Françoise Labbé.

Zoning of activities increases energy efficiency. The spaces for employment and community use are placed in the shadow zones of the housing terraces, this avoids the tendency for summer overheating of workspaces and the need for energy-wasting fan-driven ventilation or air-conditioning. The workspaces are lit via large north-facing roof lights to ensure adequate daylighting and reduce the energy demand for artificial lighting.

Insulation levels are considerably higher than those required by the Building Regulations. The buildings benefit from a 300 mm 'overcoat' of super-insulation to the roofs, walls and floors. This keeps in the warmth, so that sunshine, human activity, lights, appliances and hot water provide all the heating needed. High quantities of thermal mass provide enough heat storage to prevent overheating in the summer and to store warmth for slow release in the winter.

[107] This box draws on BioRegional Development Group 2002.

Triple-glazed, krypton-filled windows with low-emissivity glass, large panes and timber frames further reduce heat loss. Well-sealed doors and windows give a good level of airtightness. Heat exchangers in the passive, wind-driven ventilation system recover up to 70% of the heat from the outgoing stale air.

INTEGRATE ENERGY SYSTEMS AT NEIGHBOURHOOD LEVEL

The neighbourhood scale allows integrating hybrid combinations of renewable energy systems (including waste-to-energy) that maximize efficiency. For maintaining the security of supply and performance, communities need a mix of intermittent energy sources (solar and wind), waste incineration, and biomass. Utilities and regulators can secure that the global renewable mix is properly diversified at the system level. Key components such as energy storage should be in place to ensure grid reliability. C40 Cities and McKinsey estimate that cities could build a 50–70% renewable energy grid (especially solar and wind, balanced with other sources of zero-emission production like hydro) by 2030. This level would represent 35–45% of the total emission reductions needed during this period. Cost could be as low as 40–80 USD per megawatt-hour[108]. Adding local cogeneration plants – powered by renewable sources from the waste streams coupled with a renewable supply such as wind or solar power – can fine-tune the grid. Transitioning to a more diversified and distributed power grid using cogeneration makes the power system more resilient.

Integrating energy systems at neighbourhood level comprises four steps

- Reduce losses
- Implement cogeneration
- Integrate with district energy systems
- Close the loops of energy and waste flows

Reduce losses

Losses must be reduced in the conversion chain from energy supply to end use. By analysing current energy systems, we can trace losses and identify effective interventions in terms of cost and environment. Typically, centralized energy systems waste more than two thirds of their energy in generation, transmission and consumption. Every kWh saved at the consumer side equates to at least 3 kWh worth of energy that does not need production. Energy conservation at the end-user level translates into substantial savings at the production, transmission and distribution side, no matter which resource system we are looking at.

Implement cogeneration

Cogeneration is the sequential generation of two useful energy forms from a single primary energy source. Typically, they are mechanical and thermal. Also known as combined heat and power (CHP), it captures heat, a by-product of electricity generation in a power plant. Efficiency of conventional power plants is only about 35%, while the remaining energy is lost. This loss in the conversion process is mainly heat. By utilizing this heat, the efficiency of a power plant can reach up to 90%[109]. Cogeneration offers reduction of costs and the ability to reduce CO_2 emissions. This extremely efficient use of energy requires the coordination of energy supply with local physical planning by city governments. In Scandinavian countries, cogeneration heats buildings with the hot water produced during electricity generation. In Finland's cities, over 80% of the heat demand in buildings is met from community electricity production.

Integrate with district energy systems

District energy systems are networks of underground insulated pipes. They pump hot or cold water to multiple buildings in a neighbourhood or city. Such systems establish synergies between the production and supply of heating, cooling, domestic hot water and electricity, and can be integrated with municipal systems such as power, sanitation, sewage treatment, transport and waste. This enables integrated energy grids that fuel low-carbon, energy-efficient heating and

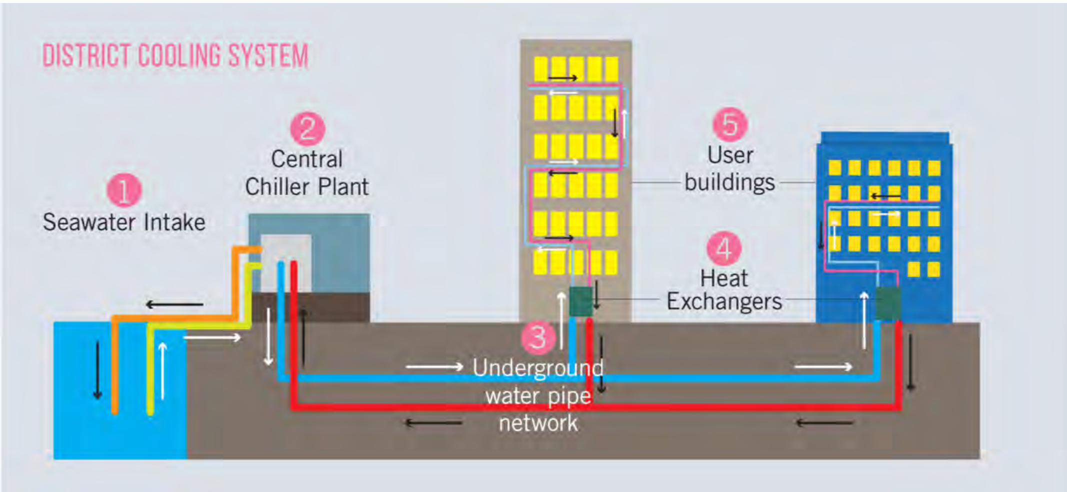
[108] C40 Cities and McKinsey 2017.
[109] Mohanty and Ou, 1997; Mohanty 2011.

cooling, and maximize local renewable resources. Sweden has a long history of integrated district energy systems. Over 50 years ago, Stockholm began creating the infrastructure for district heating. Now it accounts for nearly 80% of all heating[110]. Today, 80% of the energy used for district heating in the City is renewable, energy from waste or residual heat.

District energy is suited to feed in locally available, renewable and low-carbon energy sources: solar thermal and geothermal heat, waste heat from industry and commercial buildings, heat from combined heat and power plants. The ability to integrate diverse sources means residents are not dependent upon a single one. More efficiency, more renewables and more flexibility lead to a more resilient system.

In District Cooling systems, a chilled water piping network distributes the cooling. Such systems have been used for more than 40 years. In Japan, hundreds of them act as high efficiency heat/cooling supply systems for central business districts[111].

The change from a centralized to a decentralized energy supply creates however new challenges in the planning of such energy supply concepts. Specialized planning tools that can cope with the complex requirements and boundary conditions of local energy use are therefore needed. Existing methods need to be further developed and optimized to suit the complex stakeholder structures encountered in innovative district projects.



District cooling systems. Source: Hong Kong 2017.

Close the loops of energy and waste flows

Waste must first be recycled. Once reprocessing options have all been explored, waste can become an energy source. Generating energy from waste and closing the loops increase local energy production. Since neighbourhoods continuously produce waste flows, by not throwing them away and capturing their energy potential, waste converts into a major source of renewable energy supply along with wind, solar, and geothermal power. All forms of combustible waste can become a primary fuel for cogeneration. When waste is conceived as an energy source, it's a resource rather than a cost.

Waste to energy opportunities are of two types

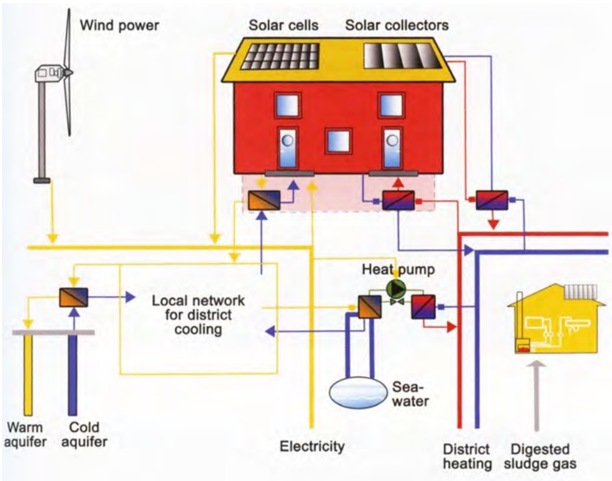
- ***Waste-to-energy biogas generation*** employing sludge, organic food waste, and green waste.
- **Neighbourhood scale cogeneration** using biofuels and combustible waste.

[110] LSE Cities 2013.

[111] UN-Habitat 2012.

CASE STUDY: INTEGRATED ENERGY SYSTEMS IN Bo01 MALMÖ[112]

Malmö Bo01. Photo: ©Françoise Labbé.



Energy system diagram for Bo01. Source: Formas. Redrawn by Ariel Utz.

Bo01 in Malmö has three important natural resources for renewable supply
-a favourable average annual wind speed.
-good solar radiation.
-seawater and groundwater aquifers, which act as heat sinks.

Bo01 integrated system takes advantage of these three local sources.

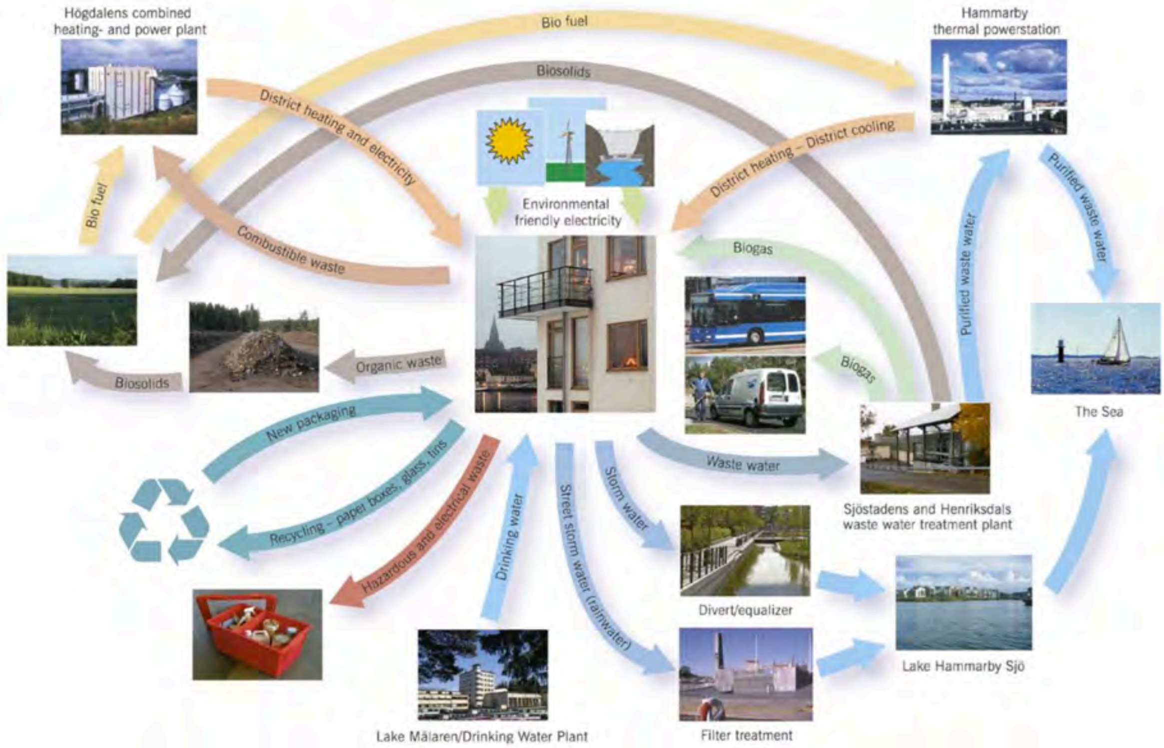
[112] This box draws on Fraker 2013.

–A two-megawatt (MW) wind turbine, on the coast one mile north of the site, delivers electricity to the dwelling units and powers a large heat pump system that distributes hot and cold water to the neighbourhood.
–A 120 m array of photovoltaic cells on edifices augments the electric supply: 1400 m2 of solar collectors, both evacuated tube and flat plate, are installed on the roofs and facades of buildings.
–The groundwater aquifer and sea water, used as a heat sink, provide seasonal storage. Heat is extracted from the units in summer. It is stored in the aquifer until winter and dispatched by the heat pump. Cold extracted from the units in winter is stored in the aquifer, and is delivered by the heat pump in the summer.

The electric, heating, and cooling systems are connected to the city grid and district systems to have them act as a storage, offsetting any mismatch in production and consumption. When energy output of Bo01 exceeds usage, the excess is sent to other parts of Malmö. When the local production of Bo01 is insufficient for the activity, the neighbourhood receives energy from the city systems. The system is designed to have the local renewable supply equal the demand on an annual basis. Bo01 is one of the first neighbourhoods in the world that supplies 100% of its energy from renewables and back it up with measured performance data.

CASE STUDY: THE WASTE-TO-ENERGY PROGRAMME IN HAMMARBY SJÖSTAD

Waste collection systems in Hammarby Sjöstad. Photos: ©Françoise Labbé.



The Hammarby model.

The Hammarby model uses neighbourhood waste streams for generating energy and recovering heat. It is the closest any system has come to eliminating the concept of waste. In the Hammarby model, energy is captured from three waste flows.

–The first burns combustible garbage to power a local district heating and electric cogeneration plant.

–The second recovers heat from the sewage treatment system.

–The third converts sludge to biogas for cooking (1000 units) and to power local buses.

Total energy from waste is estimated at 31.3 kWh/m2/y (25.4 kWh/m2/y for heating and 5.9 kWh/m2/y for electricity).

The first step is diminishing the initial flow of waste. Hammarby Sjöstad set the goal of reducing solid waste by 15% by weight, and, further, has taken the most comprehensive approach by recycling or reclaiming all the remaining flows. Actions are

–Use recycled materials where environmentally and economically feasible.

–Deposit no more than 20% of construction waste in landfills.

–Sort and gather all solid waste (glass, plastic, metals, and paper) using a vacuum system at locations around the site, and then recycle it. The system eliminates the transportation energy and pollution caused by garbage trucks.

–Collect combustible waste and convert it into district heating and electricity.

–Collect and compost garbage (organic waste).

Integration of waste collection system into the green landscape of Hammarby Sjöstad. Photo: ©Françoise Labbé.

The energy supply goals are
–Supply 50% of the energy demand on-site.
–Supply district heating by a heat recovery plant that uses purified wastewater from the site as a heat source.
–Provide district heating and electricity by a cogeneration plant that burns combustible waste from the site, with additional biofuels obtained off-site.
–Incorporate limited arrays of solar photovoltaic cells and solar hot-water panels to demonstrate and test new technology.
–Generate biogas from wastewater sludge for city vehicles.

CASE STUDY: INTEGRATED POWER SOURCES IN BEDZED, THE UK[113]

The main source of energy is a Combined Heat and Power (CHP) plant which runs on chipped tree waste. The CHP has been sized so that over the course of a year it generates enough electricity to provide for all of the development's needs, this makes BedZED a zero-fossil energy development. Waste heat from electricity generation provides hot water for the homes and offices. This is distributed via a district heating system of insulated pipes. Water of constant temperature is delivered to oversized domestic hot water cylinders positioned in cupboards located within each dwelling. The cupboards can be opened to double up as radiators in cold spells. Additionally, the homes are fitted with one small radiator and a heated towel rail.

The CHP generator engine is fuelled by a combustible mix of hydrogen, carbon monoxide and methane gases, produced from woodchips by an on-site gasifier. These come from local tree waste which would otherwise go to landfill. The CHP

[113] This box draws on BioRegional Development Group 2002.

is approximately 30% more efficient than conventional electricity generation as productive use is made of heat energy that would otherwise be wasted. Generating on-site also avoids the losses in transporting energy via the high-voltage National Grid.

Photovoltaic panels allow electricity to be generated directly from the sun's energy. The development boasts 777m^2 of high-efficiency mono-crystalline PV panels integrated into the sunspace roofs and the CHP building.

BedZED. Photo: ©Françoise Labbé.

ELECTRIFY THE NEIGHBOURHOOD ENERGY WITH RENEWABLES

Electrification has a high potential for climate change mitigation. Compared to coal, electricity generated by hydro, wind, solar and geothermal power can bring substantial decreases in emissions for greenhouse gases (by more than 90%) and for pollutants harmful to human health and ecosystems (by 60–90%)[114]. Decentralized electrification technologies can provide access to modern energy services to one billion people currently deprived of them. It can enhance energy security and diminish exposure to global energy price volatility. It can strengthen the resilience of the energy system to natural hazards. It can reduce the costs of outdoor air pollution[115].

The rapid fall in prices is driving the trend. Since 2009 the total installed costs of solar and offshore wind turbines have decreased by nearly 70% worldwide, with onshore wind costs on course to drop by 50% through 2030[116]. In many contexts, it is now more economical to bring new solar power online than to continue to operate coal plants[117]. Onshore wind has become the world's lowest-cost energy source for power generation, with US$30–60 per megawatt hour (MWh), which falls below the range of the most affordable fossil

[114] UNEP 2015.
[115] New Climate Economy, 2018.
[116] Frankel et al. 2016; Dykes et al. 2017.
[117] Frankel et al. 2016.

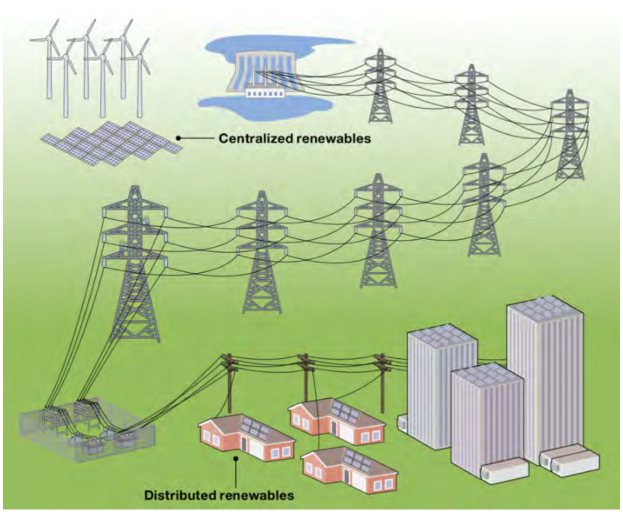
fuel, natural gas (US$42–78 per MWh)[118]. Utility-scale solar PV is the second-cheapest energy source[119]. Moreover, cost savings have been achieved in a range of power technologies over the last decade. For instance, the unit cost of small-scale photovoltaic systems has decreased fivefold since 2008, sensors by more than 95%, and battery storage by more than two thirds (mainly through the implementation of electric vehicles). The average cost of a smart metre has dropped by about 25%, with nearly 600 million smart metres put to use worldwide[120].

Deployment of community renewable energy enables consumers to access electrification or exercise choice. Adding storage and management systems offers greater flexibility and renewable integration. In off-grid areas, community renewables can now provide electrification at the same price and performance parity with other options. In on-grid areas, its ability to power communities independently of the network fulfils the goals of resilience. Many countries have adopted community energy to democratize access to the benefits of renewable energy deployment.

The natural environment in and around a neighbourhood determines its renewable energy strategy: how much solar, wind and other renewable resources are accessible to create the balanced mix needed for grid stability; whether it is cheaper to build power plant projects in remote areas or smaller facilities near or in the city; and whether the risk of floods, storms or other natural disasters justifies a focus on decentralized systems. Regional variations in the price and availability of renewable solutions also affect the feasibility. These encompass labour costs and experience in design, development and operation of renewable assets.[121]

An integrated energy plan comprises a diversified mix of energies, both centralized and decentralized. It leverages economies of scale in centralized systems. It benefits from efficiency gains of local renewable energy.

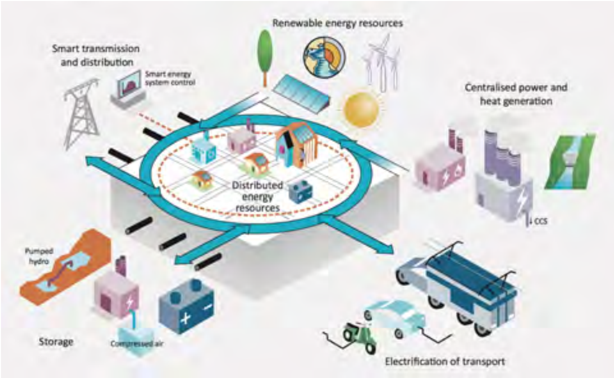
For some types of renewable energy, such as offshore wind, centralized generation is the minimum cost-effective scale[122]. Cities around the world, such as Copenhagen, Melbourne and San Francisco, have paved the way for a massive expansion of centralized renewables.



Centralized and distributed renewables. Source: C40 and McKinsey 2017.

Distributed renewables in the city fabric such as rooftop and community-scale solar PV have an important role to play and require optimization of the urban form. Smaller facilities within cities may be cheaper for utilities and potentially faster to implement. For example, New York City's utility Con Edison has chosen to invest US$200 million in distributed renewables and demand decrease technologies, allowing it to postpone the building of a new US$1.2 billion substation[123]. On-site generation, such as rooftop solar PV, combined with on-site storage, can reduce peak energy demand – for instance during hot summer days that otherwise would require costly construction of centralized peak load capacity.

[118] Lazard 2017.
[119] The high end of solar PV's cost range (US$43–53/MWh) is lower than that of any other generation source. (Lazard 2017).
[120] IEA 2017b.
[121] C40 and McKinsey 2017.
[122] C40 and McKinsey 2017.
[123] Bade 2016.

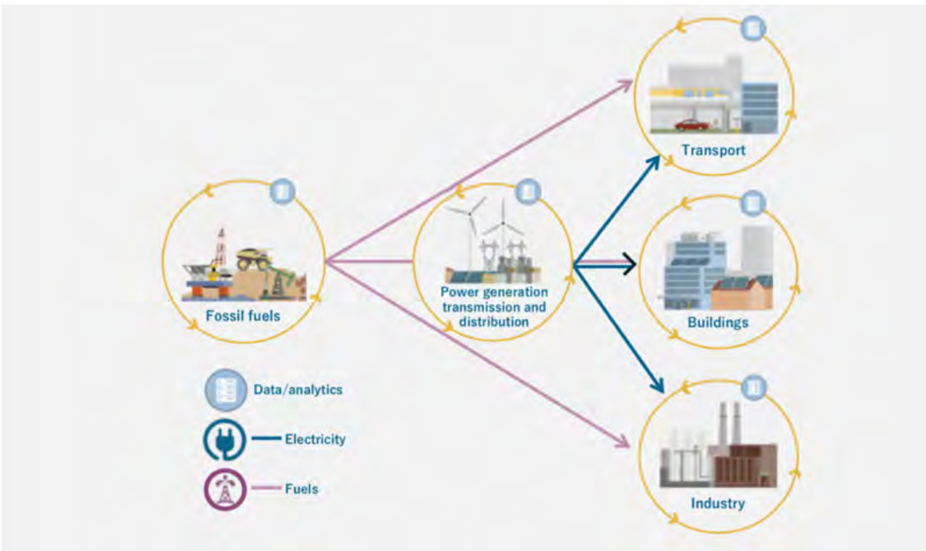


The integrated and intelligent electricity system of the future. To combine all elements of electricity systems will add complexity, but improve operations, efficiency and resilience while optimizing energy resources and investments. Source: IEA 2014.

When combined with micro-grids and local storage, distributed renewables increase resilience. They enable neighbourhoods to restore power quickly after natural disasters and other disruptions in centralized service. Hot water produced in local cogeneration plants can be delivered to the district heating system and to the units. This makes local district heating systems self-sufficient from any interruption in the citywide system. Local renewables can feed a local 'smart grid' that supplies the units and is linked to the utility grid for providing energy backup. In this model, rather than a large citywide grid, a network of self-supplying neighbourhoods 'smart grids' operates independently with the citywide grid as a framework and backup. The community microgrid can thus be protected from any interruption in the regional or citywide electric grid. When renewables are combined with cogeneration, the local grid can absorb the intermittency of wind and solar supply. Cogeneration ensures actually resilience in both directions – it supplies balance and back up to local renewables. It can also provide additional backup to the regional grid. Neighbourhood scale micro utilities incorporating cogeneration are a critical means of integrating renewables while creating greater resilience for the whole system.

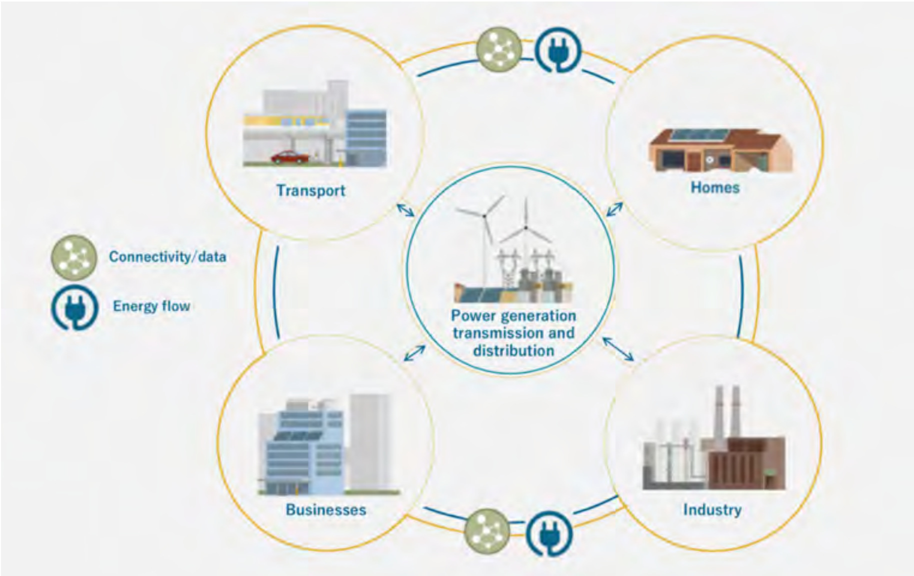
INTERCONNECT WITH SMART GRIDS

Traditionally, electricity has been generated in large power plants, transferred by transmission and distribution networks and distributed to end users in the residential, commercial, industrial and transportation sectors. This model is about to change drastically. Over the next few decades, digital technologies should make energy systems around the world more connected, intelligent, efficient, reliable and sustainable. Remarkable advances in data analytics enable a range of new applications. Digitized energy systems could in the future identify those who need energy and deliver them at the right time, in the right place and at the lowest cost.



Traditional structure of the electricity sector. Source: IEA 2017b.

Connectivity, combined with electrification and decentralization, holds the potential to create a highly interlinked system, transforming the way electricity is supplied and consumed.



Digitized structure of the electricity sector. Source: IEA 2017b.

Digital technologies transform the electricity system through four key drivers

- Smart demand response to provide the flexibility needed to integrate more variable renewable energy generation.
- Integration of variable renewable energy sources.
- Implementation of smart charging of electric vehicles.
- Emergence of small-scale distributed electricity resources, such as domestic solar photovoltaic energy.

The digital transformation blurs the distinction between supply and demand. It offers consumers the possibility to interact directly to balance demand with real-time supply. It facilitates a greater share of distributed energy resources, turning consumers into 'prosumers'. By adapting demand to needs in real time, digital transformation offers millions of consumers as well as producers the opportunity to sell electricity or provide useful network services. Connectivity is the key factor. It allows the linkage, monitoring, aggregation and control of many individual power generation units and consumer equipment. These assets can be large or small, for example a photovoltaic solar installation on the roof of a house, a boiler on an industrial site or an electric vehicle.

New tools such as blockchain will accelerate such local energy exchanges. A blockchain is a growing list of records, called blocks, that are linked using cryptography[124]. By design, a blockchain is resistant to modification of the data. Blockchains promise transparent, tamper-proof and secure systems that can enable novel business solutions, especially when combined with smart contracts. Opportunities of blockchains span numerous use cases from peer-to-peer (P2P) energy trading and Internet of Things (IoT) applications, to decentralised marketplaces, electric vehicle charging and e-mobility.

By 2040, 1 billion households and 11 billion smart devices could participate actively in interconnected power systems, allowing them to change when they draw electricity from the grid. This smart on-demand response could offer 185 GW of system flexibility – comparable to the current installed power supply capacity of Italy and Australia aggregated. This would save US$270 billion in new power infrastructure investments that would otherwise have been needed to ensure security of supply[125].

[124] Each block contains a cryptographic hash of the previous block, a timestamp, and transaction data.

[125] IEA 2017b.

CASE STUDY: ROYAL SEA PORT IN SWEDEN, AN INTEGRATED NEIGHBOURHOOD STRATEGY FOR ACHIEVING CARBON NEUTRALITY IN 2030

Stockholm Royal Sea Port. Top: current state. Bottom: plan for development.

Building on the lessons from Hammarby Sjöstad, Stockholm develops a new type of eco-district. Royal Sea Port is a former container port, oil depot and gasworks. It covers 236 hectares. It is one of the largest urban projects in Europe. Royal Sea Port will integrate residential buildings with commercial properties, ranging from port trade to IT, finance, and media companies. Using modern, sustainable architecture and planning, the aim is to merge 10,000 household dwellings and 30,000 office spaces with parks and open green landscape. The area will be supplied with a smart grid, benefit from a biofuel combined heat and power (CHP) system (including recovery of waste and heat) and employ on-site renewable microgeneration of electricity. Energy use will be constrained to 55 kWh/m2 through contractual obligations. The goal is to limit carbon emissions to 1.5 tCO_2e per person by 2020, and for the entire site to be fossil fuel free by 2030[126].

[126] LSE Cities 2013.

REDUCE RESOURCE USE WITH CIRCULAR MATERIAL CHAINS

Cities consume over 75% of natural resources and produce more than 50% of worldwide waste. Material use impacts the environment, biodiversity, and the climate. We extract roughly 60 billion tons of raw materials each year[127] or 22 kilograms per person per day, a 12-fold increase between 1900 and 2015. In the past 40 years alone, the global consumption of materials has almost tripled, and is expected to double again by 2050[128]. The traditional buy-use-dispose model has encumbered garbage dumps and incinerators. Waste typically accounts for 10% direct emissions in most cities[129]. Major sources are solid waste landfills and wastewater[130].

Opportunities arise from the waste market expansion, the increasing scarcity of resources and the availability of new technologies. The two most promising areas are reprocessing and energy production. Recycling is likely to grow steadily and be a key component of greener waste management systems while providing decent jobs. However, in developing countries, waste disposal often exceeds the financial capacity of many municipal governments, and the health impact – particularly for low-income communities – should not be underestimated.

SHIFTING TO A CIRCULAR MODEL

The current economy is linear. Things are made with virgin raw materials, employed and then thrown away. In contrast, circular economy keeps goods and materials at their highest value for as long as possible, through recirculation and remanufacturing. It delivers products as shared services. Shifting towards such a model has multiple benefits: expense savings from diminished resource use, emissions decrease, and inclusive jobs. The Circularity Gap report[131] estimates that circular economy could create between US$380 to US$630 billion in annual net material cost-saving opportunities. McKinsey research shows that in the mobility, food, and built environment alone, circularity could lead to emissions reductions of 48% by 2030, and 85% by 2050, compared with 2012 levels[132]. Cities around the world, such as London, are already experimenting with interventions that exploit synergies between different sectors. As a commitment to circular economy concepts in urban planning, some cities have gone as far as pledging 'zero waste to landfill' as a strategic goal[133]. They promote fair access to goods and services, sharing, and higher resource efficiency, rather than ownership and linear material flow.

Three principles

Three principles characterize circular economy[134]

- ***Value preservation***: maintaining the highest possible value from input materials in manufacturing processes and final products. This involves repurposing, refurbishing, repairing and reusing components.
- ***Resource optimization:*** limited, efficient and lessened intake of primary resources combined with improved waste collection, recycling, energy recovery from material incineration and use of renewable sources.
- ***System effectiveness***: minimizing leakage during the production/consumption cycle and addressing externalities such as land, air, water and noise pollution.

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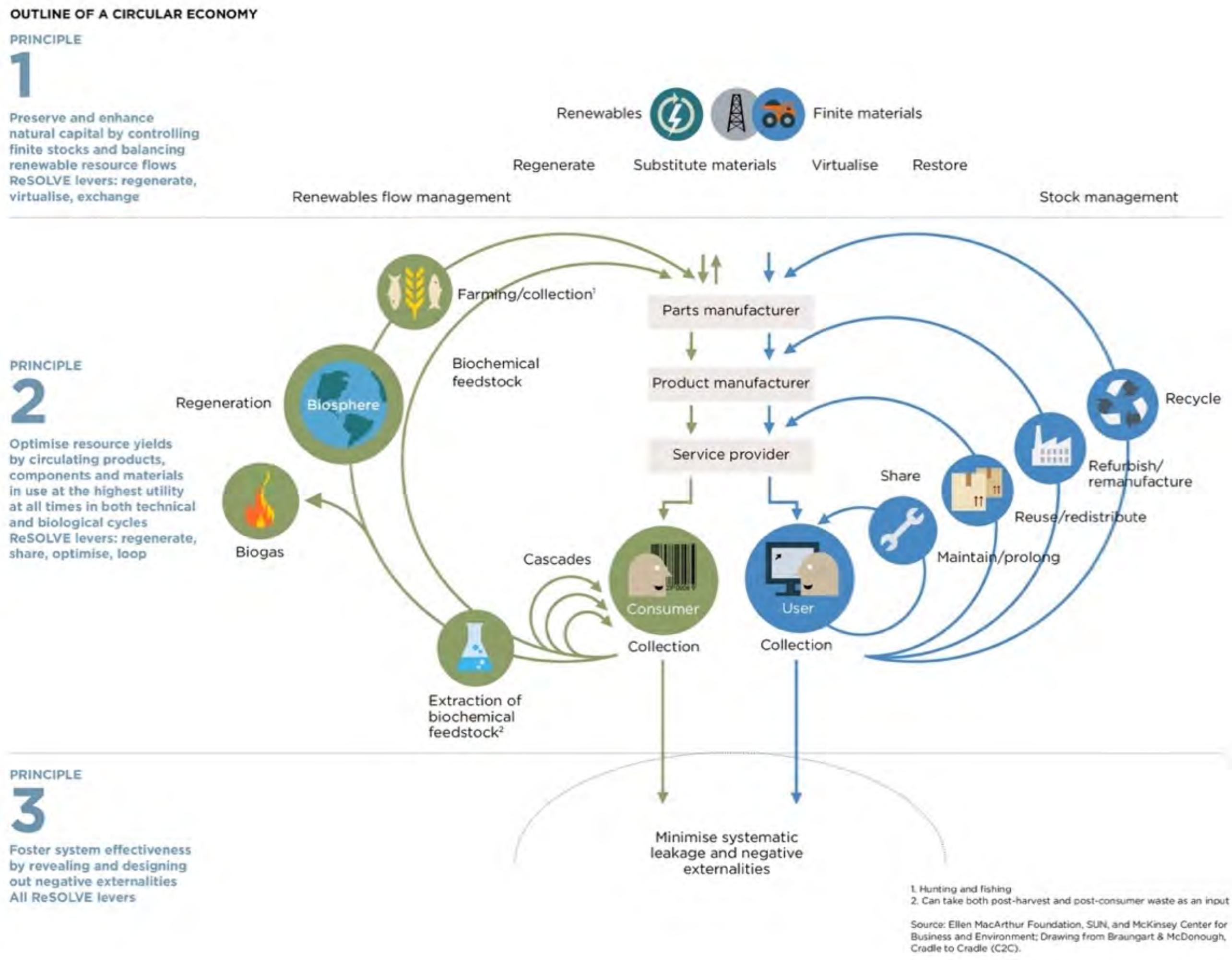
127 Haas et al. 2015.
128 World Economic Forum 2018.
129 C40 and McKinsey 2017. Waste has a disproportionate impact on global warming and on consumption emissions of the complete life cycle: 97% of global direct emissions from waste is methane, a greenhouse gas with 86 times the near-term global warming potential of carbon dioxide, making it an urgent priority for preventing the worst effects of climate change (UNEP 2015).
130 About 11.2 billion tons of solid waste is collected annually around the world (Baumert et al. 2005).
131 Circle Economy 2018.
132 McKinsey Center for Business and Environment 2015.
133 World Economic Forum 2018.
134 Ellen MacArthur Foundation 2015.



Circular economy system diagram. Source: Ellen MacArthur Foundation 2013.

Circular neighbourhoods

In circular communities, spatial planning ensures proximity between production and population. This fosters integration of resource flows. The layout and design of neighbourhoods change the way materials and products move around them. Instead of throwing them 'away' to landfill or incineration, a distributed system of resource management, nutrient flows, and reverse logistics makes the return, sorting, and reuse of products possible. People have access to what they need – whether space, products, or transportation – in innovative ways: through sharing, or through product-service contracts. Approaches such as *car-sharing* and *driving as a service* modify the use of cars and reduce the demand for new vehicles and related materials[135].

Planners should ensure that the community physical structure promotes the efficient reuse, collection and redistribution of resources such as water, organic materials, industrial by-products, building components and household recyclables. Strategies include measures to diminish the input of virgin materials, improve the use of existing assets and reduce the volume of waste. Circular economy also transforms the arrangement of elements within neighbourhoods. Modular design of infrastructure, buildings and products makes easy to maintain and repurpose them.

[135] Automobiles dominate the transportation and mobility sector. However, a typical car is parked and idling for nearly 95% of its life (ArkInvest 2014). With over 1.2 billion motor vehicles on the road, this represents a significant amount of resources that are underused and wasted.

The materials are not harmful, come from indigenous and renewable sources. Local skills increase as the focus is on decentralized and distributed production. Digital material banks allow knowing the composition of constructions, vehicles and products. This simplifies their repair and reuse. Creation of products and parts on demand and on-site transforms construction methods and storage requirements. The buildings are refurbished, upgrading their use. Digital platforms enable implementation by improving access to information, management of materials, tracking and logistics, transparency and accountability, facilitating deployment of innovative circular solutions. Products are no longer employed only once. People repair and renovate them. These activities take place at the individual and community levels. Vehicles and infrastructure, from roads to streetlights, are operated and maintained in such a way that materials, energy and water are utilized efficiently, and can be reused and recycled.

A Roadmap and Action Agenda: The City Circle Scan Method[136]

The City Circle Scan is a roadmap and action programme for circular economy implementation. The method comprises four phases.

- **Mapping of material flows and added value**
  The main flows of materials and energy are examined, supplying information on the material flows in and around the city. Activities and places are assessed for their ecological impact. The analysis provides insight into where and how to create value and opportunities for job growth and economic development.
- **Evaluation and selection of chains**
  A comprehensive analysis of value chains connecting multiple sectors is undertaken. Founded on macroeconomic statistics, this phase determines in which chains the actions can obtain the most important circular effect. The result is a prioritized list based on the following indicators.
    - ecological impact
    - economic significance
    - value preservation
    - transition potential
- **Visioning**
  This phase develops a prospective vision. It explores how the identified chains can work in a circular future. It shows how chains and their interactions can be configured differently. It formulates strategies. It is tested and refined through feedback sessions and interviews with experts and stakeholders.
- **Project selection and formulation of actions**
  An action programme with scheduling and implementation for launching relevant circular projects is developed. Governments, research institutes, businesses, entrepreneurs and citizens work together to circulate the identified chains. The roadmap formulates time paths for policy interventions. It indicates the key actors for a successful transition. Activities are evaluated on four main effects.
    - value creation
    - CO_2 reduction
    - material savings
    - employment growth

Scenario building and planning

UNEP developed a spatial microsimulation urban metabolism tool, called CE-Jobs, that combines two powerful approaches for the simulation of resource flows within cities: spatial microsimulation (SM) and urban metabolism (UM)[137].

Unlike other tools that model policy impacts on a city-wide level, CE-Jobs provides insights on groups in the community, broken down for instance by income, education, age, or household size. This can be of great value for cities to make sure that their policies are fair and reach everyone in the population, which aligns with the New Urban Agenda[138] and the Sustainable Development Goals[139].

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[136] Adapted from: Circle Economy, TNO and Fabric 2016.
[137] www.resourceefficientcities. org/resources/smum/
[138] UN Habitat 2017.
[139] United Nations, General Assembly 2015.

The CE-Jobs tool can

- Support the downscaling of national-level data for use at the local level in data-scarce environments.
- Include a spatial element in scenario planning estimations to ensure equitable allocation of resources during circular economy transitions.
- Help the calculation of circular economy jobs and their distribution.

CASE STUDY: SITE-SPECIFIC PLANNING FOR MATERIAL FLOWS AND RESOURCES RECAPTURE IN A LONDON NEIGHBOURHOOD

Old Oak high street after redevelopment.

London incorporated circular economy principles into the draft plan for the regeneration of Old Oak and Park Royal. The scheme aims to create more than 25,500 new homes and 65,000 jobs on 640 hectares of residential and industrial areas. Optimal circulation of local materials will develop an 'exemplary world class neighbourhood underpinned by new business models, and new cultures of collaboration, innovation and community engagement[140]'.

The main opportunities identified in the current planning phase relate to buildings and infrastructure. With resource efficiency, sharing and adaptability, structures can be reused and disassembled. By capturing local resources such as water, heat, organic substances and solid waste for reuse and underutilized zones for agriculture, the draft plan aims to ensure the area environmental and economic resilience.

140 ARUP et al. 2017.

CASE STUDY: INTEGRATING SORTING WASTE AND PUBLIC TRANSPORT RIDERSHIP INCREASE IN CURITIBA, BRAZIL[141]

Curitiba. Aerial view of Batel and Água Verde neighbourhoods. Photo: Francisco Anzola.

As the city of Curitiba grew, garbage accumulated in narrow lanes where trucks could not recover it. The city developed a programme explaining to children how to separate it; the children, in turn, taught their families. In return for the selective sorting of waste, residents were paid in fresh food or bus tokens, which increased healthiness and the public transport system ridership. Today, 85% of citizens in Curitiba use the bus and 90% participate in reprocessing. The city recycles 70% of its waste, one of the highest rates in the world.

DEVELOP CIRCULAR CONSTRUCTION CHAINS

Urban population growth will create the need for more infrastructure in cities: 75% of the infrastructure required by 2050 is not yet in place[142]. The cost of renovating old infrastructure and building new one is estimated to US$41 trillion until 2030[143]. However, if the building industry continues to use traditional methods, it could have devastating effects on the environment, the atmosphere, natural resources, health and the economy[144]. The construction sector consumes 40% of the materials entering the global economy. A large share of these are extracted minerals: sand, gravel and limestone for cement manufacture[145].

[141] Source: McDonough 2017.
[142] Global Infrastructure Basel Foundation 2014.
[143] IRP 2013.
[144] For example, the construction chain is responsible for 40% of Amsterdam's total waste stream (CBS 2014).
[145] Building materials account, for instance, for around 40-50% of the carbon footprint of an office building (cement and steel production account for almost 80% of the energy used during construction), with the remainder going to transportation of materials, waste disposal and on-site energy consumption (Circle Economy and Ecofys 2016).

Construction immobilizes these materials in physical structures for relatively long periods (long-term stock). The embodied carbon contributes to a significant part of a building's lifetime carbon footprint. Four categories of building products are among the most carbon intensive: cement, reinforcing bars, structural steel and ready-mixed concrete[146].

Builders must thus adopt a holistic and systemic approach to design, construction, maintenance, operation and use. Taking a life-cycle approach would lower embodied energy and emissions. Affordable materials and technologies can decrease the carbon intensity of future infrastructure in developing countries. For instance, cement can be engineered to absorb more CO_2. In a circular construction chain, architects design buildings so that materials will have the longest possible lifespan through reuse or repurposing. The benefits of circular economy in building feature

- reducing the need for new construction.
- improving urban land use.
- diminishing production and operating costs.
- increasing resource efficiency.
- strengthening the local economy.

A study in Amsterdam[147], for instance, has shown that by organizing the construction chain in a circular way while fulfilling the growth ambition to realize 70,000 new homes by 2040, the municipality can obtain a 3% productivity increase worth 85 million euro per year. This economic growth is achieved by the retention of value because of the recycling of materials and efficiency enhancements. Productivity increases lead to employment opportunities: over time, about 700 additional jobs can be created. The improvement in material reuse saves 500,000 tons of material, which is significantly compared to the current annual import of 1.5 million tons of material. Greenhouse gas emissions are expected to decrease by half a million tons of CO_2 per year, which corresponds to 2.5% of the city of Amsterdam's annual CO_2 emissions.

Circular economy approaches in buildings

- Taking inspiration from nature
- Planning for local circular material flows
- Integrating material choices into design
- Sourcing materials strategically
- Buildings reused and refurbished instead of demolished
- Increasing the use of space through design features
- Buildings intended for adaptability, so that they can be disassembled at the end of their life. Smart design makes them more suitable for repurposing and for the reuse of materials
- Buildings that use innovative products and technologies to be more circular
- High value recovery and reuse of materials and components
- Buildings deconstructed to trigger maximum material reuse. Streamlined dismantling and separation of waste streams authorizes high-value reuse
- Innovative business models enabling flexibility and efficiency
- Durable infrastructure that can adapt over time
- Constructing 'buildings as material banks' (BAMB)
- Marketplace and resource bank: exchanging commodities between market players

[146] Cement production is the third-largest source of human-made emissions after fossil fuel combustion and land-use change, contributing about 5.6% of global fossil fuel and industry-related CO_2 emissions. Bai et al. 2018.

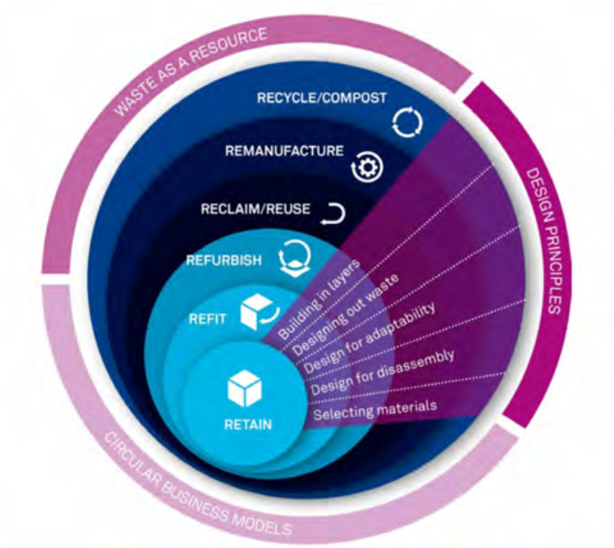
[147] Circle Economy, TNO and Fabric 2016.

A hierarchy for circular economy strategies in buildings

The diagram below[148] defines an order which maximizes the use of existing materials. When moving through the hierarchy outwards, returns diminish. Refurbishment and reuse are preferable option to recycling waste produced by the demolition process.

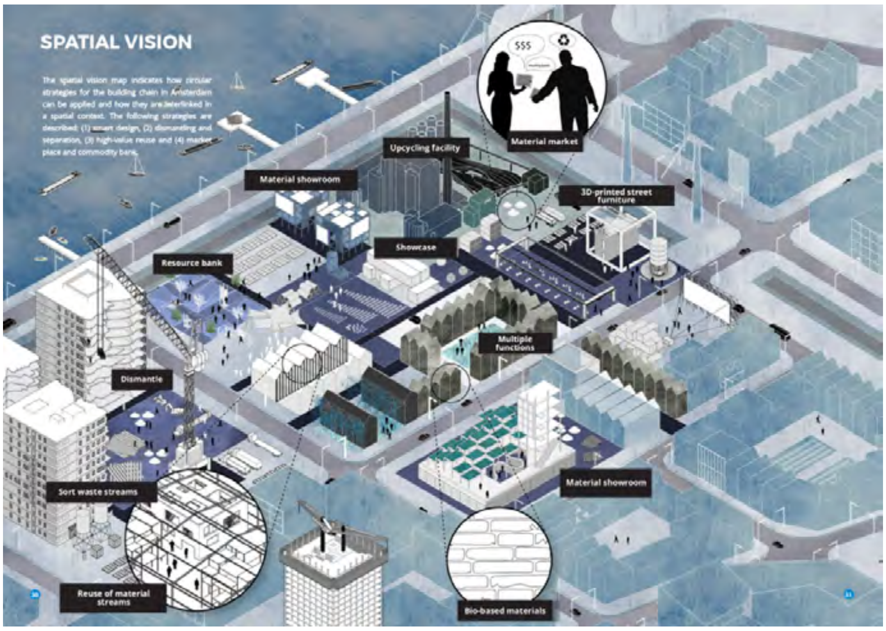
Key design principles support the hierarchy.

- Building in layers – ensuring that different parts of the construction are accessible and can be maintained and replaced.
- Designing out waste.
- Designing for adaptability.
- Designing for disassembly.
- Selecting materials – for example, those that can be reused and recycled.



Applying circular economy to the built environment. Source: Cheshire 2016.

Integrating a Circular Construction Chain in Four Steps[149]



Spatial vision for a Circular Construction Chain in Amsterdam. Source: Circle Economy, TNO and Fabric 2016.

[148] Cheshire 2016.

[149] Adapted from Circle Economy, TNO and Fabric 2016.

- **Smart design**

Living and working spaces must be sufficiently flexible and customizable for adaptation to changing economic patterns. This is possible through modular and flexible design, 3D printing, bio-based materials, and experimental construction areas.

  - ***Modular and flexible design.*** The versatility of multipurpose buildings ensures a longer life, with continuous adjustment to the varying demands of occupants. Modular construction can support a quick and economical adaptation of different building functions, reducing the number of vacant spaces and optimizing available space.
  - ***3D printing.*** Innovative technologies, such as 3D printing, can play a pioneering role in diminishing costs and using materials. They lead to less waste and offer the opportunity of material creation (e.g. of biological provenance).
  - ***Bio-based materials.*** New, sustainable materials of biological origin can contribute to smarter buildings.
  - ***Regulations*** to enable the creation of modular buildings with flexible uses and cutting-edge materials. By changing building codes, developers have more space to experiment and more freedom to practise circular designs.

- **Dismantling and separation**

When demolishing structures, separation of reusable products and materials should allow retaining their commercial value. Dismantling constructions efficiently and splitting their waste streams allow better reuse of their materials and elements.

  - ***Decommissioning.*** In a circular construction chain, the economic model shares equitably the costs and benefits of a longer lifespan between partners. The costs for each partner are monitored during all life phases: design, construction, maintenance, operation and demolition. Contracts authorize the reuse of components and materials. They can be sold to offset the costs of destruction.
  - ***Waste separation.*** Dividing construction and demolition waste allows recovering materials with a higher value without cross-contamination.

- **High value recycling and reuse**
  - ***Better reuse.*** Construction waste materials can be reworked into new products.
  - ***Demolition clean materials.***
  - ***Retrieving materials*** *from street furniture and paving.*
  - ***Repurposing existing buildings.***

- **Marketplace and resources bank**

Each building is a bank filled with valuable materials. However, after decommissioning, separation and recycling, a gap still exists between demand and supply. High value reuse is therefore a major challenge. A comprehensive online market and logistical support system facilitate the exchange of materials between demolition, construction and recycling companies. Besides, a physical location must store these materials, called a ‘resource bank’.

CASE STUDY: THE RESOURCE ROWS IN ØRESTAD, COPENHAGEN, THE FIRST RESIDENTIAL AREA CONSTRUCTED WITH RECYCLED BRICK MODULES FROM VACANT EDIFICES.[150]

The Resource Rows in Ørestad, Copenhagen. Drawing by Lendager Group.

Existing structures hold untapped potential for material extraction for utilization in new properties. Across Denmark, abandoned houses and commercial premises are available to be dismantled. Copenhagen, where dwelling demand is robust, is working to improve the sustainability of new buildings by using recycled materials. This enables reducing CO2 footprint by up to 70% compared to traditional construction methods. An innovative technique allows upgrading the brick facades of old buildings that are ready to be demolished. The strength of the mortar makes it impossible to recycle individual bricks. The walls are therefore cut into modules for the new facades of buildings.

DEVELOP A CIRCULAR ORGANIC RESIDUAL STREAMS CHAIN

The cultivation and processing of wasted food – ending up in landfills and releasing methane – consumes significant amounts of land, water and energy. This exacerbates greenhouse gas emissions – while 815 million people were undernourished in 2016[151].

In circular organic residual streams, food and water of the highest quality are delivered to consumers; innovative applications recover and reuse organic remainders. At the core of this circular vision are integrated food production, food processing and biological processes, where nutrient and water flows are efficiently channelled and residual streams are valorised. This leads to a more diverse chain of organic waste streams that requires less energy, nutriments, water and resources and offers significant economic, environmental and social benefits.

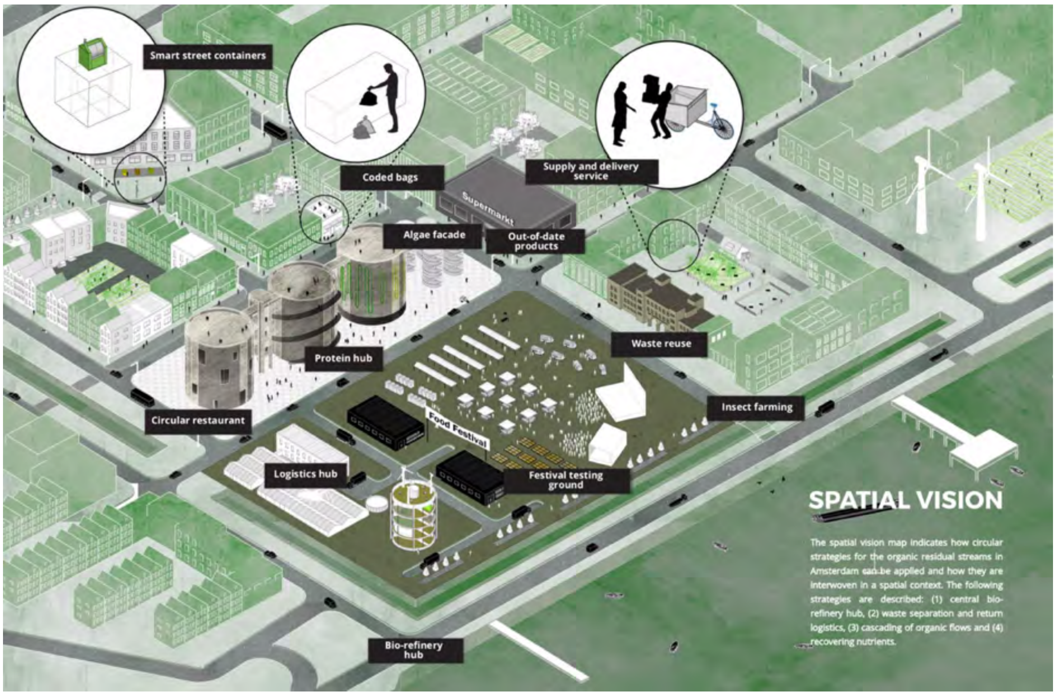
In a circular future, local cooperative farms nearby neighbourhoods will provide direct supply of fresh seasonal produce to residents. The food chain will be shorter. By smartly utilising underused rooftops and communal spaces for agriculture and gardens, community residents will have easier and closer access to fresh food. Innovative technologies for food distribution and storage offer opportunities for

[150] Source: Lendager Group 2017.

[151] Food and Agricultural Organization 2017.

documentation and management of food products. Smart logistics systems will continuously monitor the food quality and ensure its transportation on time. Neighbourhoods will become biorefinery centres, dealing with organic waste streams that can no longer be reused profitably. The separation and treatment of mixed and homogenous waste streams by producers, consumers and retailers will allow to recover important nutrients and employ them in the agricultural sector. Processing these flows will offer opportunities for new packaging solutions, biochemicals, biofuels and biogas products that can be exported or used locally.

Integrating a Circular Organic Streams Chain in Four Steps[152]



Spatial vision for a Circular Organic Streams Chain in Amsterdam. Source: Circle Economy, TNO and Fabric 2016.

- **Central biorefining centre**

A hub for the valorisation of organic waste streams from households allows to extract, through cascading, their highest possible value. These activities can be grouped in a bio-refinery and a logistics centre where bulk products and small local flows can come together. This enables implementation of the following.

  - ***Cascade optimization of residual organic flows.***
  - ***Bio-based materials.*** Their use is an important opportunity to reduce the impact of rare building materials.

- **Waste separation and return logistics**

Good waste separation and smart reverse logistics allow the optimal valorisation of organic streams. They make it possible to deploy the logistics hub smartly and to increase the value of residual flows. Fruit and vegetable waste, for instance, can be used for the production of green gas as a transportation fuel, and serve as raw material for the manufacturing of biochemicals.

- **Cascading Organic Flows**
  - ***Cascading of organic residual streams to high-value applications.***
  - ***Development of high-quality protein.*** Algae grown from organic wastes can be processed into a wide range of by-products such as animal feed, fertilizers, fuels, chemicals and pharmaceuticals.
  - ***Biomass in public spaces.*** Untapped areas can be used in a smart way for the production of biomass.

[152] Adapted from Circle Economy, TNO and Fabric 2016.

- **Recover Nutrients**

Recovering essential nutrients closes their cycle. Across the whole food chain, only 5% of the nutrients placed in the soil are actually used to provide us with nutritional value[153]. The remaining 95% are lost somewhere in the cycle. Opportunities can be found in fertilizer manufacturing and decentralized processing.

CASE STUDY: MULTIPLE BENEFITS OF CIRCULAR ORGANIC RESIDUAL STREAMS CHAINS IN AMSTERDAM

The high-value treatment of organic waste streams for the city of Amsterdam can, over a period of five to seven years, generate an added value of 150 million euros per year. In the long term, this action will create 1,200 new jobs. The material savings could reach nearly 900,000 tons per year, a considerable amount compared to current annual imports of 3.9 million tons of biomass for the entire metropolitan area. They consist mainly in replacing materials by higher value treated waste streams[154]. The future circular scenario features the source separation of organic waste in the 430,000 households in Amsterdam. Separate collection directs the flow of organic waste to new uses, such as the manufacturing of protein for animal feed, biogas and building blocks for the chemical sector, including the production of bioplastics. The expected reduction in greenhouse gas emissions is in the order of 600,000 tons CO_2. This represents almost 3% of Amsterdam's annual CO_2 emissions[155].

[153] Circle Economy 2014.

[154] For example, the production of high-quality protein from organic waste can replace imported proteins such as soybeans for animal feed, and the production of bioplastics could replace the production of oil-based plastics.

[155] Circle Economy, TNO and Fabric 2016.

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