The new logic of environmental sustainability under the smart everything paradigm

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Abstract
The environmental sustainability challenge is not new. Concerns about the impact of human activity on the environment have been growing constantly since the mid-20th century. The projected global population growth, intense urbanisation, the adoption of energy and materials-intensive industrial processes in all countries are drivers towards ecological imbalance. Therefore, most solutions for sustainable growth focus on the way we build cities, manage industries and expand transportation infrastructure. The paper starts from discussing the big sustainability challenges of fossil fuels, greenhouse emissions and climate change, pollution of natural ecosystems, waste and water management in cities. Then, we examine two cases: (a) the current sustainability practices or how solutions are organised by smart growth city planning, New Urbanism, and Leadership for Energy and Environmental Design (LEED-ND) principles, and (b) the logic of sustainability that goes together with smart cities, sensors and the Internet of Things, and the new science of environmental applications. We show that the smart everything-smart city paradigm is changing the normative aspects of environmental sustainability. It is opening up new routes to sustainable futures and new ways in which environmental sustainability can be achieved. Instead of planning focused on land uses, compact cities, buildings, and green infrastructures, this paradigm proposes solutions that motivate citizens' behaviour towards dematerialisation, renewable energy, limiting pollution. Awareness, behaviour change and optimisation are leading the sustainable use of resources. The paper is based on Chapter 9 of my book *Smart Cities and Connected Intelligence: Platforms, ecosystems and network effects*, Routledge, Regions & Cities, 2020.

Key words: sustainability, environment, pollution, smart urban growth, sensors, IoT, behaviour change

1. Grand challenges of environmental sustainability

The concept of sustainability refers to processes that can continue indefinitely. Among the different aspects of sustainability (environmental, economic, social) environmental sustainability holds a pre-eminent position due to catastrophic collapse that risks associated with it may bring. Sustainability as a challenge is a combination of (a) an evidence-based assessment about harmful human activities over nature and human-induced climate change, and (b) a normative statement about how human activity can restore ecological balance and maintain the planet's life-support system and living ecosystems (Mason, 2011).

Environmental sustainability is relative to our level of capabilities and know-how: "the concept of sustainable development does imply limits - not absolute limits but limitations imposed by the present state of technology and social organization on environmental resources and by the ability of the biosphere to absorb the effects of human activities" (Brundtland et al., 1987, p. 16). From this perspective, the Brundtland report (1987) focused its policy recommendations on topics that cannot be sustained by available resources, such as such the growing world population; the food security and the food gap in regions where it is more needed; the preservation of species and natural ecosystems, with species disappearing at rates never before witnessed on the planet; the energy challenge and the trend of developing countries to meet industrialised countries' energy consuption; wide use of fossil energy in manufacturing, transport and housing; and the urban growth challenge. The urban challenges are more intense in developing countries and regions, where few city governments have the power, the resources, and the management capacity to provide services and facilities for decent human life to a rapidly growing population.

Goals and programmes on current sustainability challenges by global organisations do not converge around a common set of priorities. The United Nations introduced the 2030 Agenda for Sustainable Development to free humanity from poverty, secure a healthy planet for future generations, and build peaceful, inclusive societies (United Nations, 2015). In this policy document, adopted by Heads of State and Government at a special UN summit, five out of the 17 goals for sustainable development relate to the environment. The programmes of the World Business Council for Sustainable Development give priority to the circular economy, cities and mobility, climate and energy, food and nature. Nature Conservancy points out the increasing demand for food, water, energy and infrastructure to serve 9 billion people on the planet are pushing nature to its limits.

These divergences aside, there are three common themes that run across the priorities set: (a) climate change and renewable energy, (b) making cities green and sustainable, and (c) sustaining terrestrial and natural ecosystems. At the level of causes, the greatest challenge is environmental sustainability's dependence on the dominant economic growth model and established energy-intensive and material-intensive forms of production. Addressing this challenge, the 'ecological modernisation' approach, which advances the greening of production through technological innovation and eco-efficient corporations, is not sufficient. The weakness is that 'ecological modernisation' falls short of the economic dematerialisation and decarbonisation that are necessary to deliver environmental sustainability. In particular, the efficiency gains from less intense energy and material use in developed countries will be wiped out by the increased material and energy consumption in developing countries and the increase in the world's population (Mason, 2011).

Climate change, fossil fuels and carbon emissions challenges have intensified. In twenty years, from 1995 to 2015, the global CO_2 emissions have increased by 50%. There has been constant and linear growth since 1950. The larger part of emissions is due to burning fossil fuels, cement production and gas flaring, and a minor contribution comes from deforestation and land use changes, driven by agriculture and the expansion of urban areas. By 2016, the largest producers of CO_2 were China (28.1% of total volume), USA (15.99%), India (6.24%), Russia (4.53%), Japan (3.67%). Among the 10 largest producers, only one comes from the EU, Germany, contributing 2.23% to the total CO_2 volume. A major contribution comes from developing counties. CO_2 emissions from developed countries have stabilised, while those of developing counties continue to grow rapidly (UN-DESA, 2013, p. 14-17). The stabilisation of emissions in developed countries is partly explained by the relocation of industry away from the most advanced regions and the growing imports of emissions-intensive products from developing countries, mainly China. In parallel, it can be explained by the rapid turn of the EU and US to renewable energy, where by 2017 renewable energy production accounted for almost 50% of new energy capacity. Projections for the future of emission and global warming depend on assumptions about economic and demographic growth and technological developments for replacing fossil fuel by renewable energy. Scenarios that foresee a 4^{o}C increase of the average surface temperature by 2100 compared to temperatures in 2000 contain too many uncertainties to accurately outline 80 years foresight. Causal associations that trace down the impact of greenhouse emissions to anthropogenic climate change are multiple and complex. They include increases of temperature, changes in precipitation intensity, the frequency of extreme weather, flooding and droughts, the melting of glaciers and polar ice caps (Dodman, 2009; Hansen and Sato, 2004; Shine et al., 2005).

Pollution of terrestrial and natural ecosystems is a factor threatening the life of ecosystems which adds to deforestation, population growth in the tropics, tropical timber exports, and climate change (Brundtland et al., 1987). Atmospheric warming leads to the upward shift of treelines and fauna, an increase in insect pests and tree mortality. Lower precipitation affects soil moisture and the increase in drought and tree density. Pollution generated by human activities is a people-killer, affecting about 100 million people worldwide. Thousands of people die because of drinking unclean water. The health effects of air pollution have been extensively studied. It is documented that people in high-density air pollution regions have a higher risk of dying from lung cancer. Exposure to air contaminants and ozone has been associated with increases in mortality and hospital admissions due to respiratory and cardiovascular disease (Brunekreef and Holgate, 2002). Heavy metal pollution from mines increases carcinogenic and other risks due to soil pollution with heavy metals, especially for children and those living in the vicinity of heavily polluted mining areas (Li et al., 2014).

Cities in stress add another layer of complexity. A survey in 90 cities around the world (26 in North America, 25 in Europe, 21 cities in Asia, 9 in Central and South America, 6 in Africa, and 3 in Oceania) (Rode and Floater, 2013) identified as top environmental challenges those related to pollution and adequate infrastructure. Top among them, by order of significance, are: (a) air pollution, (b) severe storms and flooding, (c) waste processing and disposal, and (d) water pollution. In a second part, the survey investigated four topics of importance for green growth, such as land use and transport; eco-districts and buildings; waste, recycling and energy; and electric mobility and renewable energy.

The combined challenge generated from the use of fossil energy, greenhouse gas emissions and climate change, pollution of terrestrial ecosystems, and environmental conditions in cities, forms a nexus of wicked problems. At its core, we find two drivers of environmental degradation: (a) the unprecedented rate of urbanisation, with a global urban population rising from 0.751 billion in 1950 to 4.2 billion in 2018 and expected to reach 6.4 billion in 2050 (UN-DESA, 2013), and (b) the structural alignment of energy-intensive and material-intensive production to economic growth. Very indicative of the urban change is the visualisation graphic of UNICEF 'An Urban World' that depicts the explosion of the world's urban population from 1950 to 2050, consistent with world urbanisation prospects (https://www.unicef.org/sowc2012/urbanmap/). Both urbanisation and the established growth model have high inertia, which is extremely hard to change. The spatial concentration of people in cities pushes further material-intensive growth, together with the rapid expansion of slums in developing countries.

2. Environmental sustainability mainsteam: Smart Urban Growth, New Urbanism, LEED-ND

Concerns about the negative impact of urban growth and urban sprawl on the environment emerged in the early 1970s. Since that time, the principles of 'Smart Growth', 'New Urbanism', 'Transit-Oriented-Development' and 'LEED-ND' have defined the dominant model for the sustainable development of cities.

The first use of the concept of 'smart growth' was to assess that "spreading urbanization can be costly for our environment, our society and our future" and discussed how urban design contributes to making cities sustainable (Maret and Blakeman, 1970). However, it was the adoption of 'smart growth' as an urban and transportation theory by the American Planning Association in 1995 that contributed to this planning model being established as an explicit regulatory framework for sustainable urban development (Meck, 2002). 'Smart Growth America' was founded in 2002, promoting smart urban growth principles and design in the United States and the vision of making cities "economically prosperous, socially equitable, and environmentally sustainable place to live" (https://smartgrowthamerica.org/our-vision/). Currently, the mainstream meaning of 'smart growth' in the urban planning literature refers to a way of developing cities that protects open areas, natural resources, and agricultural land; promotes compact growth with a focus on mixing uses and facilitating public transport as well as pedestrian traffic; promotes a larger variety of homes both in terms of typology and affordability; and re-designs city infrastructures to reduce energy and water use and promote the recycling of materials.

Similar concerns and planning principles can also be found in 'Transit-Oriented Development' (TOD) agenda, focusing on the design of residential or commercial areas in cities that maximise access to public transportation. TOD promotes eight principles (walk; cycle; connect; transit; mix; densify; compact; shift the land occupied by vehicles) that reduce the dependence of cities on private cars. TOD neighbourhoods are made of a centre comprising a public transit station, surrounded by high-density areas and lower-density developments gradually spreading outwards from the centre (Holmes and van Hemert, 2008). The resulting compact city form has similar environmental impacts to 'smart growth' on limiting sprawl and favouring sustainable urban development.

In 1993, Calthorpe published *The Next American Metropolis*, a book about the ecology of cities and communities, and how ecological principles of diversity, interdependence, scale, and decetralisation shape suburbs, cities, and regions. The impact of cities on the natural environment, he argues, depends on the type of settlements, their form, and technologies used in making them. The Americal Metropolis he argues is the sum of the city, its suburbs, and the surrounding natural environment. These aspects are inseparable and the failure to see them as a whole is the cause of many contemporary problems (Calthorpe, 1993). In the same year the 'Congress for the New Urbanism' was founded, inspired by similar ideas. CNU has been "responsible for creating and popularizing many now-common urban development patterns and strategies, including mixed-use development, transit-oriented development, traditional neighborhood design, integrating design standards into affordable housing, and designing complete and beautiful streets" (CNU, n.a). New Urbanism is a planning movement that focuses on designing attractive, successful and cohesive neighbourhoods with connectivity upon a dense street grid network; mixed land uses and diversity of shops, offices, apartments, and homes; quality design with an emphasis on beauty, aesthetics, human comfort; traditional neighbourhood structure with a discernable centre and edge and rich public space; highest densities in the town centre and progressively less dense settlements towards the edge; green transportation with high-quality trains connecting cities, towns, and neighbourhoods; use of bicycles, scooters and walking as daily transportation; minimal environmental impact from development and its operations and eco-friendly technologies, respect for ecology and natural systems, and energy efficiency (Sijpkes, 2001).

'Smart Urban Growth', 'Transit-Oriented Development' and 'New Urbanism' form a conceptual and planning model for environmetally sustainable communities and cities, promoting both the understanding of cities as living ecosystems as well as principles for the preservation of natural resources and ecosystems. They have contributed to establishing a very influencial planning standard, with the same principles and turning them into an operational instrument for assessing and implementing the sustainable growth of cities. We are, of course, referring to "LEED for Neighborhood Development" (LEED-ND), which was jointly developed by the U.S. Green Building Council, the Natural Resources Defense Council, and the Congress for the New Urbanism.

LEED-ND is a subcategory of LEED (Leadership in Energy and Environmental Design) which is the most widely used green building rating system in the world. It has been used in about 100,000 projects for sustainable building, energy and water saving, recycling and less waste, support of human health in cities, in over 165 countries. LEED was introduced in 1993 by the Natural Resources Defense Council (NRDC) and from 1994 to the present day it has evolved as a comprehensive system of interrelated standards for environmental leadership and excellence.

Table 1: LEED-ND environmental sustainability logic - Three areas and ten principles

Location and Linkage	Neighbourhood Design	Green Infrastructure and Building
1. Preferred locations 2. Reduce automobile dependence 3. Preserve ecological habitat and wetlands	4. Compact and open development 5. Mixed land uses and diversity 6. Multimodal transit 7. Quality of public space	8. Energy efficiency and renewable energy 9. Water management and reduction 10. Building reuse

Source: Adapted from LEED-ND, v4, 2014

The LEED-ND focuses on city districts and neighbourhoods and assesses their energy and enviromental excellence in three main domains: (a) location and connectivity to the wider area, (b) design patterns and internal organisation, and (c) green infrastructure and building. In a reverse engineering approach, these assessment criteria can be transformed into design principles, guiding the choice of location, the internal design of neighbourhoods, and the deployment of green infrastructure.

The environmental logic of location in LEED-ND (v4, 2014) is based on 14 criteria, of which 5 are a prerequisite and 9 provide credits towards the overall score for the certification level. Altogether, the problem to resolve concerns the selection of the best location for a city district or neighbourhood, which optimises the use of energy and public transport and has minimal environmental impact. Preferred locations are those that comply with the compact city and with sites placed within or close to existing city boundaries. Preferred locations are also those enabling green mobility or reduced automobile dependence. Locations which, due to existing infrastructure, provide access to quality transit, connect to multimodal transportation or limit the need for motor vehicles in daily transit. Prefered locations are also those preserving ecological habitats and wetlands. Locations should be avoided in areas with identified imperilled species and ecological communities, in which species listed as threatened or endangered are found or are likely to be found. Locations should also preserve water quality, the natural hydrology and biodiversity, and the conservation of wetlands and water bodies.

The environmental logic for neighbourhood design in LEED-ND is assessed with 18 criteria, of which 3 are a prerequisite and 15 provide credits. These fall into four major design categories: compact and open; diversity; multimodal transport; and quality of the public space. Design for compact and open development is done to achieve high density development: in residential areas 12 or more dwelling units per acre (DpA) (7 DpA for components outside walking distances) and in non-residential areas a floor-to-area ratio (FAR) of 0.80 (0.50 FAR or greater for components outside walking distances). Design for mixed land-use and mixed income communities is needed to sustain social diversity in the neighbourhood. This is achieved by mixing land uses and clustering diverse uses in accessible local and regional centres; by including a variety of housing sizes and types both for rental and for sale; and by promoting community-based food production and increased access to fresh produce in neighbourhood gardens, community-supported agriculture, and proximity to farmers' market. Access to multimodal transport, open spaces and transit facilities encourage the use of public transport and reduce total travel (VMT) by providing safe and convenient transportation means. The overall aim is to shift towards green transportation with networks connecting cities, towns, and neighbourhoods together; and pedestrian-friendly design that encourages the greater use of bicycles, rollerblades, scooters, and walking as daily means of transportation. The environmental logic of 'Neighbourhood Design' combines the control of private building and land uses, the design of public spaces, and the provision of public transport. These are large-scale interventions and operations. They presuppose large-scale public interventions and regulation to control individual practices for buildings and land use. They also require significant public investments in transport infrastructure, mass transit facilties, and quality open public spaces. Public policy is dominant is this type of environmental sustainability design.

The environmental logic of green infrastructure and building is promoted with 4 prerequisite criteria and 17 that provide credits in the assessment. The three main principles promoted deal with energy efficiency and renewable energy; water use reduction; and reuse of buildings and materials. Altogether they encourage green building practices and energy-efficient building, which lower air, water, and land pollution and improve environmental conditions throughout. Energy efficiency and renewable energy are promoted with the selection of the right solar orientation of buildings; district heating and cooling that cover most of the neighbourhood's annual heating and cooling energy needs; identification of heat islands and use of high-reflectance and green roofs, non-roof site paving with plant material, shade with architectural elements, and solar reflectance paving. Water management and reduction concerns both indoor and outdoor use. Building reuse adds environmental quality by extending the life cycle of buildings, saving resources, and by reducing waste and environmental harm from materials manufacturing and transport in new construction. It goes hand-in-hand with the preservation of historic buildings and cultural landscapes.

The assessment of LEED-ND environmental impact is positive. The US Green Building Council estimates that LEED-ND green building principles can reduce energy use by 24-50%, CO_2 emissions by 33-39%, water use by 40%, and solid waste by 70%. This is a quite substantial environmental benefit. Along the same lines, Crotty et al. endorse the LEED-ND environmental goals to reduce greenhouse gas emissions, independence from expensive and non-sustainable energy sources, and decrease threats to human health throughout the construction and usage phases (Crotty et al. 2009). Equally positive is the assessment of Ewing et al. (2013). They predicted that miles travelled per person (VMT) in LEED-ND areas would be at 24% - 60 % below the respective regional average. The highest alternative mode shares and the lowest private vehicle trip lengths were observed in centrally located projects. More reserved, though, is an assessment by Fraker who tested the LEED-ND rating system using performance data from four neighborhoods in Germany (Vauban in Freiburg and Kronsberg) and Sweden (B001 in Malmo and Hammarby Sjostad in Stockholm). He found that the majority of the points in the rating system were awarded to items that do not reduce CO_2 emissions in a significant way (Szibbo, 2016).

3. Smart systems for environmental sustainability: Introducing a new logic and agenda

There is abundant evidence that smart environments, smart cities, the Internet of Things, in-short the main components of the smart everything-smart city paradigm, bring in a new way of addressing the environmental challenges of climate change, pollution, and cities in stress (Komninos et al. 2019a; Komninos et al. 2019b). Sensors, smart meters, big data and analytics, cloud-based solutions are becoming mainstream IoT-based solutions for a better environment (Kakderi et al. 2019). Sensors and IoT can measure, track and locate a wide variety of factors that affect the environment. Apart of monitoring, they enable the optimisation of various systems: traffic and transit mobility, parking availability, the operation of energy and use of green energy, waste collection and water systems, city policing against crime and public safety against disasters. Large-scale sensor networks are deployed in Rio de Janeiro, Brazil's second largest city, the cities of Santander, Singapore, London, Seoul, Montreal, and Chicago. Many smaller cities have also launched IoT networks, aiming to benefit from the deployment of digital technology for real-time monitoring and alert. The critical path is not the setting up of a sensor network in itself, but the process of data gathering, cleaning, analysis, modelling, knowledge extraction, and behaviour adaptation.

Sensors, pollution alert and behaviour change

Addressing pollution with sensors and IoT solutions targets on human behaviour. Identifying sources of pollution and understanding the effect of pollution on humans and natural ecosystems can launch a behavioural change, which in turn may modify the environment. In contrast to the environmental logic of New Urbanism and LEED-ND, which attempts to improve the physical environment of cities, IoT-based environmental sustainability focuses on user behaviour. The starting point is to get data from sensors, followed by mapping and visualisation of datasets, setting objectives to reach, increasing awareness by alert and forecasting, and producing behaviour adaptation and change. The sequence in not linear. Dashboards setting goals and alerts may run in parallel, and mapping can be improved by forecasting. But at the end, it is the change of the behaviour of users that matters.

Sensors can monitor various pollutants. A sensor generates an output signal in response to some stimulus from the environment; then this data is transmitted to a server for further processing. The sensors we installed in the City Thermi monitor temperature, humidity, CO, CO_2, NH_3, SH_2, C_2H_6O, and C_7H_8. The most important problems to resolve were energy provision and the precision of measurements. In Thermi, installation was done by City Hall on public buildings and in public spaces to ensure the uninterrupted supply of energy. Usual installation sites are traffic junctions, parks, bus stops, lamp posts, buildings, and mobile sensors on cars, taxis, trams, etc. Similar solutions were widely used in Santander. Use of photovoltaic panels is also a solution for energy provision when sensors are installed in remote areas. However, following the installation measurement precision demands frequent calibration. Sensor fault types include complete failure, mean shift, and precision degradation fault, which is usually more difficult to detect. Detection of fault precision can be automated using algorithms that quantify the dissimilarity between the probability densities of scores and actual scores (Ji et al., 2018).

Data from sensors are sent to servers, where software applications can create emissions inventories and pollution maps. Inventories gather and compute data from pollutants and help identify sources of emissions, variation of emissions through space and time, and changes from baseline scores. A good example is the UK Emissions Interactive Maps (https://goo.gl/VPDj7h). Data for different pollutants are provided by the UK National Atmospheric Emissions Inventory. The maps give emissions of various pollutants on a 1x1 km resolution. Local area statistics are also compiled from the maps and related data. Datasets can be downloaded for further analysis and study.

A parallel line to pollution mapping and dashboards is real-time alert and forecasting. It is aimed at citizens and users so as to increase their awareness and provoke a change of behaviour. In the city of Santander in Spain, a network of low-cost sensors was deployed providing data on air quality from measures taken every 15 minutes. Then algorithms are used to model the pollution variables with supervised learning methods for prediction and classification. Predictions are offered per 1-hour, 2-hour, 4-hour, 8-hour and 24-hour forecast periods. They are made possible by using machine learning algorithms, such as linear regression, regression by discretisation, RepTree, Bagging with RepTree, and others (Román, 2016).

Behaviour adaptation and change is the final aim of pollution alert and forecasting. The deployment of sensor networks across city districts, neighbourhoods and utility networks enables them to be used to collect and distribute information and may raise awareness about the environment and the origin of pollutants. Users are motivated to adopt more sustainable behaviour through the self-reward of living in a cleaner or safer environment or through some other material gain coming from games and reward systems. Public authorities can adopt more sustainable practices to save resources. The impact is measured, disseminated, and actions for sustainability are improved. The overall process is more complex than appears in a linear succession of stages. The key factor is user motivation and the conditions under which information from sensors or dashboards may induce a change in behaviour towards more sustainable living.

Smart meters and energy saving behaviour

Smart meters are devices that measure electric energy consumption and transfer measurements to the user and supplier. They enable two-way wireless or wired communication from the user to the energy supplier and vice versa. Records inform about the energy used at various time scales (daily, weekly, monthly); the cost of energy spent; and in some cases, allow goals to be set to reduce energy consumption. The records enable energy saving by optimising usage on the consumption side, informing users how energy is spent. Switches also enable appliances connected to smart meters to be turned off remotely. In parallel, smart meters enable energy production to be optimised by coordinating energy demand and consumption, reducing overproduction and offering energy that significantly exceeds actual demand.

The system usually comprises meters, displays, and software that enable monitoring, controlling, and benchmarking of energy use. It can be installed in a house as part of smart home equipment. If installed in many houses, it enables energy usage to be monitored at the neighbourhood or district level. Aggregating data from many housing units, an energy atlas can be created providing information about the use of energy at district level. Citizens become aware of usage, how much energy the neighbourhood uses and how much heat is produced. Workshops and information sharing among users may reveal practices for energy savings and potential gains. Expected savings are at around 15-20% of baseline energy usage.

When smart meters are installed as part of a smart grid, important benefits occur on the energy supplier side. These mainly include the capacity to match demand to supply. A smart grid gives energy providers the opportunity to introduce different tariff structures to support demand response and demand management. The system also enables better programming the use of solar or wind energy, and renewable energy supply to be prioritised over fossil energy. The measurement of energy consumption is done continuously and remotely. Billing is free from manual intervention. The traditional manual billing cycle, with persons going from door to door and recording meter readings, is reduced from days to minutes. When a smart meter is bypassed, it will immediately show a great and unexplained drop in consumption, which is an alert to control.

Pilot projects show that energy savings through peak load management are a major achievement of smart grids. Savings occurs by shifting loads from peak periods to off-peak periods. A pilot project in the city of Puducherry, in the southern part of the Indian Peninsula, showed that the maximum reduction could reach 58% of peak demand (Daniel et al., 2016). Two other pilots in the cities of Groningen (NL) and Austin Texas (USA) also showed that peak load balancing was also the main gain of combined smart meters – smart grids (Obinna et al., 2017).

Thus, gains from the deployment of smart meters are mainly due to changes in user behaviour in favour of saving energy and energy production planning by shifting demand from peak to off-peak periods. Additional gain comes from automation and smart meter datasets for adjustment of energy supply to demand forecast, streetlight energy savings, energy loss detection, and automatic adjustment of devices. User experience reveals that end-users also prefer technologies that automatically adjust energy use, as they were not always capable of programming the saving implementation technologies.

Sensor-based alert and infrastructure optimisation

IoT solutions offer great opportunities for the optimisation of city infrastructure. Information collected by a grid of sensors, which is connected to any kind of infrastructure and city network, allows the use of the respective infrastructure to be optimised. In such cyber-physical systems optimisation takes place because managing authorities or users adapt their practices to information and alert provided by the sensor network.

Drinking water or water for irrigation in city parks and green spaces can be monitored for pressure and flow, quality, consumption, leak detection and water loss in the system. Web-based systems that integrate smart metering, end-use water consumption data, wireless communication networks and sensors can provide real-time information on how, when and where water is being consumed (Britton et al., 2008). Then, water planning and optimisation of use becomes feasible (Stewart et al. 2010). Water leakages are another challenge. Data from cities reveal that water loss due to leakages in pipelines is about 15%-20% in cities in developed countries and may be as high as 50% of total water consumption in cities in developing countries. A sensing platform for real-time detection of pipe fractures can monitor pipe leakage with pressure sensors, hydrophones and flow meters installed at optimal locations. The sensors transmit continuous information about the condition of the pipe network and real-time data for anomaly detection. Algorithms can identify the pressure transients generated by potential leakages and localise the event to the faulty pipe with a high degree of likelihood (see for instance the LeakView at https://www.visenti.com/leakview).

IoT solutions related to waste management are mainly focused on tracking container fill levels and optimising pickup routes (Folianto et al., 2015; Kakderi, 2019). Sensors placed in waste bins can gather and communicate real-time data. Cleaning teams can see when bins need emptying. Truck drivers can obtain real-time data to perform waste collection using dynamic route optimisation (Medvedev et al., 2015). A pilot project in the city of Hull, in the northeast of England, used sensors that measure the level of fill, but also to detect a sudden motion or shaking, which triggers an alert for potential vandalism. Equally, recording a sudden change of temperature may trigger a fire detection warning. Before, waste collection teams emptied every bin without knowing if they were full or empty. Using the system, bins communicate information on fill levels and optimal times and routes for waste collections are recommended. Bins are emptied more efficiently, when they are full and before they overflow, with fewer collection vehicle journeys, and subsequent lower congestion on the roads and CO_2 emissions are cut (see, https://goo.gl/snuDM8).

Sensor-based devices and the IoT for traffic management are widely used for forecasting traffic congestion to provide route optimisation advice, inform drivers about available parking and improve parking search. Parking in among the biggest challenges to resolve in central city areas. By providing accurate real-time information to drivers about free parking places, traffic and pollution optimisation can be achieved. There is evidence that car parking search time is a substantial part of the overall car journey. A literature review of 20th century cruising for parking ranges from 3.5 to 13.9 minutes, thus influencing the journey time and consequently the traveller's choice. Moreover, on-street parking search time depends on the occupancy ratio, parking capacity, turnover rate and the place; variables which are dynamic, depending on the time and the day, and thus difficult to forecast (Belloche, 2015). A smart parking system can address such challenges by providing real-time information about unoccupied parking places. The system usually consists of four components: information gathering by sensors (placed at inspection points and in some cases using a battery that offers many years of autonomy), data transfer to a web server and control centre where software displays data on a map, information dissemination to users by a smartphone application which navigates the drivers to available parking, and e-booking access (Kharde et al., 2018). As result, parking search time may be reduced to zero as the driver is directly guided into a reserved place.

A similar architecture can be used to monitor traffic congestion and provide route optimisation by advising drivers. Sensors monitor traffic speed, send data to a control centre for processing, and a smartphone application disseminates information to users about the shortest path to follow. Several algorithms may be used to compute the shortest connection between departure and arrival nodes, such as Dijkstra's algorithm, Bellman's Ford, A*, and Floyd-Warshall's algorithms (Gandhi and Shahid, 2015). As in the case of smart parking, traffic monitoring may inform the user about the traffic situation and optimisation is achieved by the adaptation of user behaviour to traffic conditions.

4. Discussion: Engineering the end of carbon by awareness and user behaviour

The sustainability logic that derives from the deployment of smart environments and IoT solutions stands on user behaviour. We have seen that information collected and disseminated from sensors, cameras, smart meters and smart objects, enables the initiation of practices that protect against pollution; the scaling up of energy saving attitudes; optimisation of the use of infrastructures; and a contribution to complex systems leading to zero carbon cities. Human and collective behaviours are placed at the centre of this type of environmental sustainability. The bond between data, analytics, real-time guiding systems and human behaviour that is actualised and optimised by data and knowledge inputs, is the foundation of sustainability under the smart paradigm.

We may describe the entire process by a sequence that starts from: (a) the deployment of sensors and smart meters across city ecosystems, districts, neighbourhoods and utilities, which collect information from city activities, people, and supply chains; (b) information processing, analytics, knowledge extraction and dissemination to users and authorities; (c) users becoming aware and motivated to develop sustainable behaviour through realising they have a direct gain, a long-term environmental benefit, or some kind of reward; (d) public authorities obtaining information to design more sustainable policies (Tsampoulatidis et al., 2013); and (e) impact which is monitored, measured, documented, and disseminated.

The comparison between the sustainability logic under the smart everything paradigm and the sustainability promoted by the 'Smart Urban Growth', New Urbanism, and LEED-ND principles is remarkable. The two paths to environmental sustainability are radically different, having distinctive features, illustrated in Table 2. Instead of choosing the location for activities, building with compact and open forms, mixing land uses, engineering multimodal transit, and designing quality public space as happens in LEED-ND, sustainability under smart environments is based on a binary system of information processing and behaviour change, hidden within the material space of cities (Panori, 2017).

The contrast can be conceived as a top-down approach organised by LEED-ND principles, considering all dimensions of an urban district or neighbourhood and mobilising large scale-public investments, compared to a bottom-up approach based on smaller initiatives that rely on data collection and processing, and the rational behaviour of every citizen or organisation to adapt her/his behaviour to the best solution or alert offered. In short, the contrast is between material renovation in LEED-ND vs. optimised behaviour with smart environments.

Table 2: Comparing environmental sustainability solutions

	New Urbanism & LEED-ND solutions	**Digital platforms and sensor-based solutions**
Type of actions	Sustainability based on physical elements: location, district design, buildings, transport modes, public space renewal	Solutions based on informed and motivated human behaviour
Type of solutions	Institutional solutions, planning, transferable from place to place under certain conditions	Technological solutions with low level institutional engagement, easily transferable from one place to another
Type of investments	Large-scale investments across multiple city systems and domains (transportation, housing, employment, nature, buildings)	Small-scale investment, mainly on broadband infrastructure, deployment of sensor networks, software applications and e-services
Type of process	Top-down, public sector initiatives and planning	Bottom-up, public and private initiatives in e-infrastructure and e-services
Impact	Some assessments question the impact of LEED-ND solutions on CO_2 emissions	More effective, more ambitious targets, measurable and documented impact

The physical space of cities is the focus of mainstream sustainability under the logic of New Urbanism, involving long-term planning. In most countries, a renovation project can be launched by a public institution only and takes more than a decade to complete. On the other side, solutions based on smart systems and digital platforms focus on awareness and human behaviour, can take off quickly, demand less red tape, and cost much lesser.

While the advantages from the deployment of solutions that rely on smart environments compared to the mainstream approach of Smart Urban Growth, New Urbanism and Transit-Oriented Development are substantial, there are significant shortcomings and risks to be addressed. For instance, how resilient and secure are sensor-based solutions? How do they affect privacy? Should sensors, IoT, and analytics replace human decision-making? Some key challenges linked to a wide use of sensors are noted Newcombe (2014).

For many scholars, solutions should be sought in governance, institutions, and regulatory practices that are problem-led, organised as networks, moving from reactive and incremental policies towards anticipatory and integrated approaches (Adger and Jordan, 2009; Komninos and Tsamis, 2008; Gibson et al., 2013; Panori et al., 2020). There has been substantial critique of the effectiveness of 'ecological modernisation'; but equally, the barriers to institutional regulation should not be downplayed. In most cases, institutional change is hard to implement without pre-existing institutional maturity and thickness. Instead of polarising solutions as technology vs. institutions, we should seek out how to combine both and improve institutional regulation through technology.

Sustainability solutions based on smart environments and IoT have opened up new ways to dealing with the major challenges of climate change, cities in stress, and the fight against pollution in which the human dimension prevail (Angelidou et al., 2018; Kakderi et al. 2018). They offer more direct, lower cost and easy to implement and efficient solutions. The spectacular pace of urbanisation and growth of cities make this sustainability path extremely vital. However, this does not mean that smart city sustainability is incompatible with urban renovation projects and the pursuit of New Urbanism principles. On the contrary, we should consider the two approaches to be quite complementary, and sustainability based on smart environments can be added to LEED-ND principles for design and renovation.

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