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Future cities and environmental sustainability

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Abstract

Massive growth is threatening the sustainability of cities and the quality of city life. Mass urbanisation can lead to social instability, undermining the capacity of cities to be environmentally sustainable and economically successful. A new model of sustainability is needed, including greater incentives to save energy, reduce consumption and protect the environment while also increasing levels of citizen wellbeing. Cities of the future should be a socially diverse environment where economic and social activities overlap and where communities are focused around neighbourhoods. They must be developed or adapted to enable their citizens to be socioeconomically creative and productive. Recent developments provide hope that such challenges can be tackled. This review describes the exciting innovations already being introduced in cities as well as those which could become reality in the near future.

Keywords: Future cities, Sustainability, Urbanisation, Environment, Innovations

Introduction

Throughout history, cities have been at the heart of human development and technological advancements [1]. Although an element of planning can be discerned even in the earliest cities they have often evolved in response to the changing needs and aspirations of their inhabitants. Some cities have survived for millennia, including Rome, Athens, Cairo, Alexandra, Baghdad and Beijing, and are still flourishing. Other, once mighty, cities have disappeared, their ruins being unearthed by present-day archaeologists. A fascinating example, built by the Khmer civilisation, is Ankor Wat [2] in present day Cambodia, which boasted features very relevant to the design of future cities. Notable achievements by the ancient Khmer engineers were the control and distribution of water through a sophisticated canal system irrigating agriculture within the city bounds supplying citizens with ample food. The fundamental problems that the Khmer solved were the prevention of flooding by Monsoon rains, and storing water for the subsequent periods of drought. Despite its success over 8 centuries, AnkorWat collapsed in 1431 [3]. Climate change resulting in extended droughts is considered to be a contributory factor, which even the excellence of Khmer engineering was unable to counter.

Tenochtitian, the Aztec capital in what is now Mexico, was built in a lake bordered by swamps. The flow of water was controlled to provide land for building and irrigate fields, the so-called floating gardens. The city districts were connected by both causeways and canals. The Aztec engineers also had to separate the brackish water of the lake from spring water from nearby hills for drinking. In 1519, at the time of the Spanish conquest, Tenochtitian, with an estimated population of 200,000 to 300,000, and was one of the largest cities in world. Although conquered it did not collapse like AnkorWat, but was developed by the Spanish into what is now Mexico City, with a population of 21 m.

Although in designing cities of the future we have a much greater range of technologies than our ancestors, we must not make the hubristic mistake of assuming that these will ensure our success. The words of George Santayana are apposite, "*Those who do not remember the past are condemned to repeat it.*" We need an enlightened approach to design cities of the future, learning from the experience of the past and applying the advanced technologies of the present.

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Tomorrow's cities: chaotic or strategic? Lessons from the immediate past

First and foremost, future cities must serve their citizens, combining increased prosperity for all with desirable life styles. These aims must be achieved without detriment to people who live in other regions; for example they must not export carbon emissions by importing goods manufactured by fossil fuel and feedstock dependent processes or create pollution elsewhere. This is not to say that a city cannot import feedstock or energy intensive goods from outside its borders; rather the energy and material contents of imports must be balanced by those of exports. To this end, future cities must adopt wide scale utilisation of renewable energy, waste management/minimisation, water harvesting/recycling, landscape/biodiversity to enhance the natural environment, use of green transport systems, applications of innovative material/construction methods (low/zero carbon buildings) and local food production.

While such aspirations would have been familiar to city designers in antiquity, their modern counterparts can draw upon newer technologies such as integrated smart management control systems based on wireless sensor networks, which by detailed monitoring can turn wasteful cities into sustainable cities. Technologies will need to be tailored to particular geographic, climatic and cultural conditions, but all will have a similar philosophy of turning buildings from passive entities to active, adaptive and adaptable spaces that takes advantage of the surrounding environment for heat, cooling, light and electricity. A key to achieving low carbon cities is understanding how best to select and integrate various technologies from the many available, to optimise performance for different building types, climates, cultures and socio-economic conditions. A strategic approach will be required to achieve a sustainable city to ensure that it functions efficiently as a whole. But the planning parameters should not be so centralised and rigid that they do not allow different community designs and architecture styles to find expression.

Several impacts of overpopulation in urban areas are already appreciable as summarized in Table 1 with possible mitigation strategies. First of all concerns of food and water security is arising in many cities. As these cities expand, agricultural land is converted into residential and industrial areas. For instance in Conception, a Chilean City with a population of 500.000, 1734 hectares of wetlands and 1417 hectares of agricultural land and forests were transformed into residential areas between 1975–2000 [4]. In Accra, Ghana, it is estimated that 2600 hectares of agricultural land is converted every year where Chinese and Indonesian cities have the similar pattern [4]. In the future agriculture will be challenged to meet the demand of a population that is projected to grow and to urbanize. This indicates that more food will be demanded by a population of net food buyers; and food demand will have to be met by rural and peri-urban areas or by food imports.

Table 1 Impacts of global urbanisation and mitigation strategies

Impacts ⇒	*Mitigation Strategies*
High traffic density	✓ Efficient public transport ✓ Compact city design
High amount of waste	✓ Recycling
Urban warming	✓ Increasing green space, ✓ Using reflective materials
Increasing Air pollution	✓ CO_2 capture, ✓ Filtering exhaust gases, ✓ Increasing efficiency of industrial processes/vehicles
Increasing energy consumption/sinking resources	✓ Using renewable sources, ✓ Achieving low energy buildings, ✓ Increasing efficiency of devices/ processes
Lack of biodiversity/natural habitat	✓ Increasing green space, ✓ Developing animal/plant protection areas
Sinking water resources	✓ Water purification ✓ Desalination ✓ Rainwater harvesting
Rising food demand/ poverty	✓ Vertical farming ✓ Artificial food production ✓ Greening the deserts
Land shortage for housing	✓ Constructing multifunctional buildings, ✓ Creative architectural designs
Weak Social cohesion	✓ Improving sociocultural environment ✓ Increasing the number of organisations-events that bring people together

On the other hand, in many emerging cities, people are obligated to live in more marginal regions. They have less adaptive capacity, low incomes and no assets. Additionally less legal and financial protection, no insurance, no land tittle… Indeed urban areas are more attractive than rural areas for many people in terms of job opportunities, improved living conditions, multicultural environment and dynamic life. In fact developed countries are already highly urbanized due to the opportunities they have, and the United Nations estimates that the urban populations of Africa, Asia, and Latin America will double over the next 30 years, from 1.9 billion in 2000 to 3.9 billion in 2030. At that point, over 60 % of the world's population will live in cities [5].

Cities with the growing urban mass will turn to a more resource, land, food and energy demanding consumers and they should be productive to be genuinely sustainable. Unproductive urban areas will probably face with poverty, inequality of individuals, pollution, illnesses and external economical dependency.

Productivity is clearly desirable in emerging cities as it increases competitiveness thereby prosperity and sustainability of any city. More productive cities are able to increase output with the same amounts of resources, generating additional real income that can raise living standards through more affordable goods and services [6]. More specifically, the generated extra income and municipal revenue will enable any city to provide more, better services, including housing, education and health services, social programmes and expanded infrastructure networks to support both productive and leisure activities. Indeed, the productivity of the city is directly influences the citizen well-being and socio-economic status.

Urban productivity is the measure of how efficient a city transforms inputs into outputs. Gross domestic product (GDP) per capita is commonly used as a proxy for urban productivity, with a city's GDP measuring local production of goods and services and the population serving as a proxy for inputs related to human capital. GDP is an important measure of sustainability of developing cities. The report by UN demonstrates that GDP of emerging cities is significantly influenced by the national development level. The importance of national comparative advantage is illustrated by the fact that, while 22 of the top 30 largest urban areas (by population) were located in emerging or developing economies in 2008, only seven emerging economy cities ranked among the top 30 in terms of urban GDP. The group included Mexico City, São Paulo, Buenos Aires, Moscow, Shanghai, Mumbai and Rio de Janeiro, but no Middle Eastern or African cities (See: Fig. 1). The average GDP per capita of these emerging/developing country cities tends to be substantially smaller than that of developed cities [6].

The recent report by the United-Nations (2014) estimate 3.9 billion urban population in 2014 itself. The urban population will be increase about 2.5 billion, which means by 2050 UN estimates about 6.4 billion population residing in urban areas. Increasing urban population will lead to a significant increase of urban energy consumption and urban emissions. Higher population may also cause an increase in urban density (number of people per unit area). Key strategies are needed for minimizing energy consumption, efficient use of land, sustainable food production and transport. In a recent study Singh and Kennedy developed a tool for predicting future energy consumption and CO_2 emissions based on electricity, heating and transportation in urban areas [7]. The tool was applied to 3646 urban areas and three projections were used in the analysis for the years 2020 and 2050. In medium and high projection it is assumed that the number of people per unit area (km^2), (urban density), will increase 1 % and 2 %, whereas in low projection no urban density increase was assumed. The predicted emissions and energy consumption in the years 2020 and 2050 with the baseline of 2000 are given in Fig. 2a and b. The results revealed that, for the high projection, CO_2 emissions based on electricity usage will be doubled in 2020 and increase more than four times in 2050. According to the developed tool, heating sector based CO_2 emissions and energy usage will not affected from the urban density and will slightly increase in all cases. On the other hand the increase in urban density may dramatically increase the transportation sourced emissions and energy consumption.

While some cities in the past have been planned, at least in part, they have often grown chaotically with minimal strategic design and service provision, especially when under pressure from population growth often driven by migrations from the countryside during periods of agricultural mechanisation and industrialisation. The large industrial cities of 19th century Britain and the favelas of 20th century Rio de Janeiro are obvious examples. Lack of sanitation, overcrowding, disease, child labour and little provision for education resulted in the horrendous living conditions described in the novels of Charles Dickens and the factual reports of investigative journalist Henry

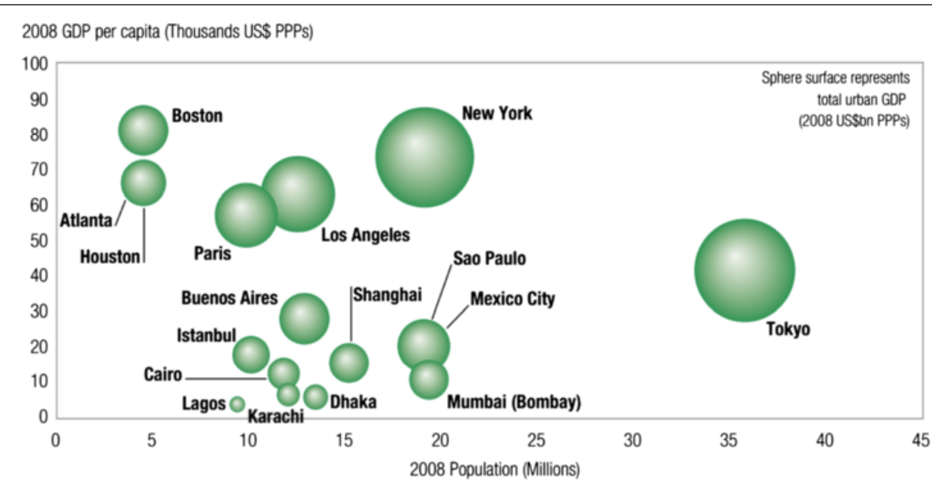

Fig. 1 Population, GDP per capita and total GDP for selected metropolitan areas (2008) [6]

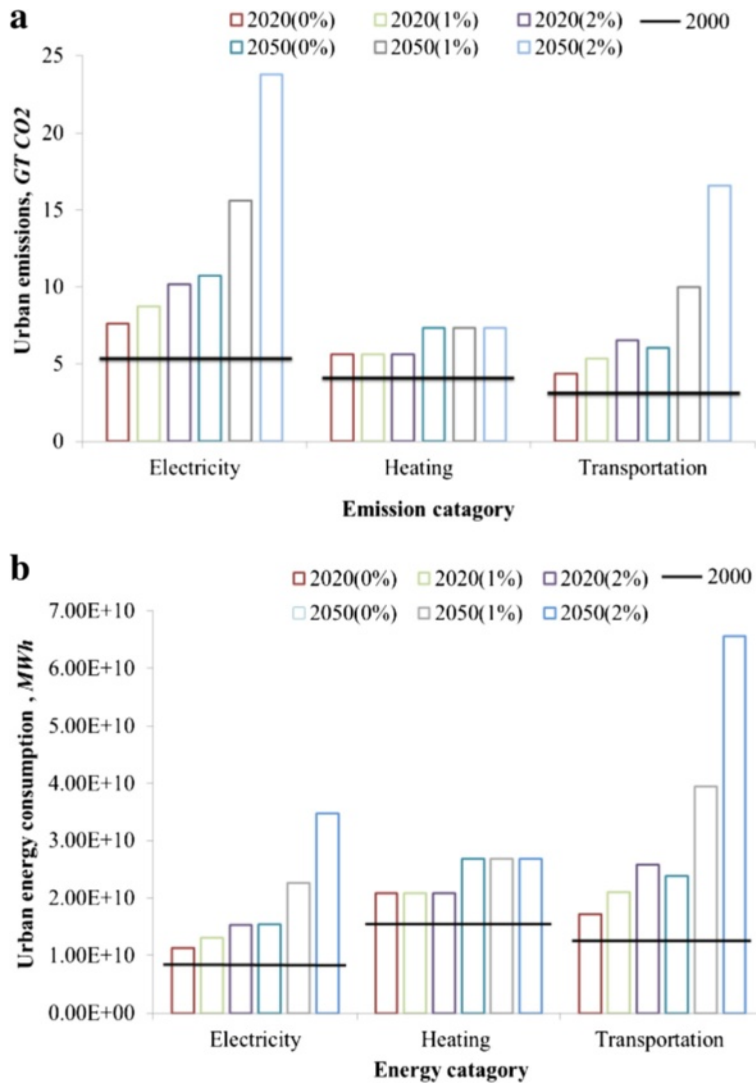

Fig. 2 Predicted sectoral urban (**a**) emissions, (**b**) energy consumption by 2020 and 2050 based on percent urban density decline [7]

Mayhew [8]. In Britain a century and a half of social reform, legislation and regulation has been required to heal the wounds of past piece-meal urban growth. Even now Britain suffers from a considerable 19th and early 20th century house stock, which whilst impractical to replace, is also technically challenging to refurbish to the modern standards of energy efficiency necessary to reduce national carbon emissions.

To avoid the chaos of the past future cities must be planned. But city wide planning, especially on grand scale, has a legacy of suspicion. Like other European nations after the Second World, Britain, embarked upon a combination of slum clearance in bomb-damaged cities and initiating new cities on greenfield sites, in part inspired by the "concrete" visions of the Swiss-French architect Le Corbusier (Charles-Édouard Jeanneret-Gris), who was active in the first half of the 20th century. Tower blocks and "streets in the sky" constructed using reinforced concrete and industrial engineering-type processes proved to be a disaster, both technically, because of lax quality standards, and socially, because of social isolation and creation of conditions conducive to petty crime. In Britain, 60 years later, these structures are regularly demolished to be replaced by more traditional low rise dwellings built to modern standards. Even in 1945 John Betjeman, the Poet Laureate, who was a staunch defender of historic buildings, warned about overpowering development in his poem "The Planster's Vision" [9] where the second verse begins with the ironic lines,

"I have a vision of the future, chum,
The workers' flats in fields of soya beans
Tower up like silver pencils, score on score…"

The key word is "chum" that implies an insensitivity for humans as individuals. On the other hand, influenced by the British planning failures of the 1950s and 60s, heir to the British Throne Prince Charles, is highly critical of "modern architecture" and strongly advocates a return to local vernacular architecture for new communities, a philosophy he has applied to the development of Poundbury in southern England [10, 11]. Charles' ideas have been dismissed as an anti-progressive pastiche of the traditional. But, in some respects, Charles is returning to the earlier vision of British urban planner, Ebenezer Howard the creator of the garden city movement [12]. Letchworth was the first garden city followed by Welwyn Garden City, both built in the early 20th century to the north of London, recognised the importance of an integrated transportation system, but, not surprisingly for the time they were built, did not foresee the rapid growth of automobile ownership. The garden city philosophy was adopted in other countries.

In summary, inspired city planning working to a well-defined strategy with a regard for human values can avoid the chaos created by the uncontrolled growth of cities during rapid industrialisation. Engineering has much to offer future city design but it must be tempered by a respect for citizen's aspirations. The designs for future cities must be flexible, responding to evolving technologies and cultural changes. With rapid global urbanisation the challenges are immense; but to learn what works new cities must be built to new designs. We shall need to accept that success will be accompanied by failure, from which we shall, and must, learn.

Review of the visions for future cities

Innovative visions are needed in emerging cities to reduce the impact on the environment while creating places that increase social cohesion, or accelerating human interaction in education, health and employment to improve the quality of life for an ever greater percentage of our world population. The technological advancements should be fully utilized to realize these visions and goals. For instance, temperature, pollution, water systems, waste management systems, radiation, traffic, air pollution and other components can be monitored through wireless sensor networks for achieving the greatest efficiency [13]. These systems can help detect leaks and problem areas quickly, potentially saving electricity and other precious resources. In order to save additional resources, cities can consider grassroots initiatives, like farmer's markets and community-supported agriculture. Urban farming is a simple change, since dirt beds can be put nearly anywhere and grow food locally [13]. Organizing community carpools and encouraging people to recycle waste and use reusable bags for shopping can make huge impacts as well. A staggering 75 % of solid waste is recyclable, but steps need to be made to encourage more recycling to happen, as 70 % is still thrown into the trash [13–15]. Cities can become also more sustainable and attractive by adding open space. Hiking trails, activity centres, and parks can draw people into the city and reduce waste.

Cities are vital to the future global economy. For instance 41 % of the UK's population lives in the country's ten largest urban areas [16]. However, cities are struggling with climate change, changes in population and demographics, congestion and healthcare, and pressure on key resources [17, 18]. In future there will be a large market for innovative technologies/approaches to create efficient, attractive and resilient cities [18, 19].

Recent research has been focused on the development of a data platform for power, heat and cooling usage in cities and individual usage patterns in domestic, commercial and industrial buildings [20, 21]. There is a lack of information in the rapidly changing energy market. Solutions are required to better handling of cost, supply and demand of energy in cities and towns. With macro-level energy data, cities can invest in new innovations, provide more focused geographic support to areas where energy supply is lacking, and gain better decision-making evidence on issues such as targeted building retrofitting and fuel poverty [21].

Responding to the rapid urban development and challenges, future cities have become a pressing issue due to the impacts of global warming problems. This inevitably requires identifying prioritizing and structuring new design and managerial tools to improve their environmental, urban and fiscal sustainability.

Emerging cities should also develop local and national policies to retain highly qualified individuals. Currently in developing world, the proportion of cities making effort to retain talented and visionary individuals is alarmingly low. Asia could count as an exception where half of the cities are putting effort to retain talent. In China, Chongqing has developed an ambitious training programme to support the transition of rural migrants from manual-based to skill-based types of work; by 2009, nearly one-third of migrants had benefited from the scheme [22]. Dubai is also promoting education especially in the fields of engineering and information technologies [23].

Some cities in developing countries have embraced the model of world-class innovation clusters, such as California's Silicon Valley or Boston's Route, to become 'high-tech hubs' [6]. Those that have met with success in this endeavour, such as India's Bangalore, owe it to the same basic factors: the presence of top-quality academic and research institutions as well as substantial public and corporate investment. However, low infrastructure development rate and unbalanced distribution of benefits of growth across all the population are signalling threat for these regions. Quality of life is rapidly emerging as a major asset in any efforts to attract and retain creative minds and businesses. It is not surprising that Toronto, San Francisco or Stockholm are regularly ranked among the top performing cities in the world, since they are found as performing particularly well in a wide range of both economic and quality of life indicators including crime, green areas, air quality and life satisfaction. Except more developed nations, Singapore, with a similar balance of quality of life attributes, also ranks among the top world cities and the highest among developing countries [6].

Inspiring from the above given successful examples, each city should develop its own strategic future vision for realizing the basic concepts, with the aim of maximizing an integrated total of environmental, social and economic values. When setting out the future vision, both a backcasting approach of looking back from a desirable future to the present and a forecasting approach of looking forward from the present to the future are essential to enhance feasibility. Moreover, it is important to set the vision in a way that fully embodies each city's diverse and unique features that arise from its natural and social characteristics. Each city is required to tackle the challenges of the environment and aging society, and is further encouraged to take on additional challenges in areas that can enhance their originality and comparative advantages in cooperation with other cities in the same nation and abroad. It will be important to gather worldwide wisdom by absorbing information on other cites' successes from all over the world, as this will help integrate a variety of efforts in different fields and realize synergistic effects. By accumulating successes, cities are expected to break away from subsidies and acquire self-financing independence, establishing financially and socially autonomous models [6].

The European "Smart Cities & Communities Initiative" of the Strategic Energy Technology Plan (SET-Plan) promotes 40 % reduction of greenhouse gases in the urban environment by 2020, which could be achieve with sustainable and efficient production, conversion and use of energy. Yet the domestic sector will increasingly become the leading energy sector as more people around the world aspire to higher living standards, which will drive the demand for air conditioning and electric power. Zero energy buildings (ZEB)/Zero carbon buildings (ZCB), therefore, expected to have a vital role to achieve sustainable and smart cities. Kylili and Fokaides define ZEBs as buildings that have zero carbon emissions on an annual basis [24]. The required ZEB aspects as part of future's smart cities are demonstrated by the Kylili, and Fokaides as given in Fig. 3.

Various designs for future cities have been mooted, some more adventurous than others. Some are actually being built. All aspire to being carbon neutral and sustainable, exploiting the latest technologies for construction, renewable energy, recycling and transportation.

Recently the British Government has announced plans for new garden cities in the UK which emphasised the development of new communities adapted to local needs [25]. The aspirational "wish list" harks back to Howard and, although arguably obvious, it does express what is expected of a future British garden city:

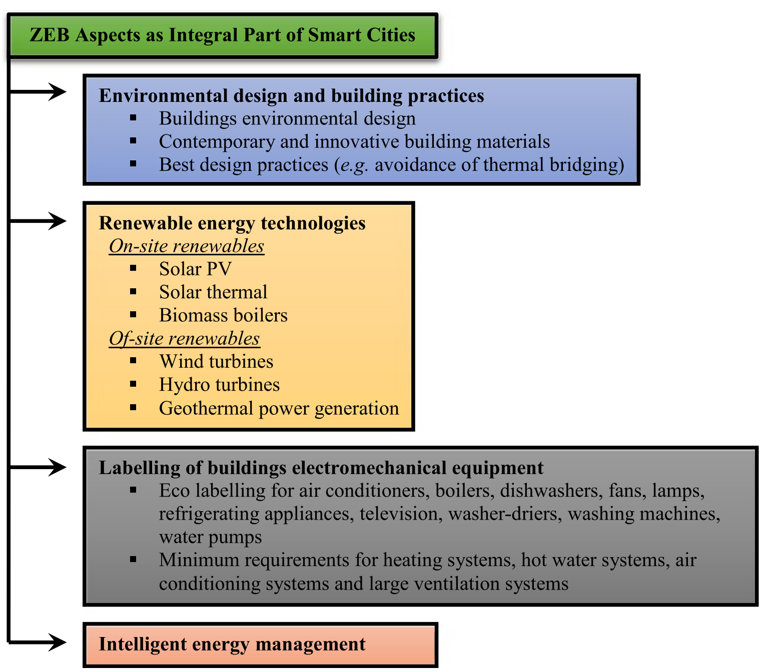

Fig. 3 ZEB aspects as integral part of smart cities. Adapted from [24]

- Strong vision, leadership and community engagement
- Land value capture for the benefit of the community
- Community ownership of land and long-term stewardship of assets
- Mixed-tenure homes and housing types that are affordable for ordinary people
- A strong local jobs market in the Garden City itself, with a variety of employment opportunities within easy commuting distance of homes
- Beautifully and imaginatively designed homes with gardens, combining the very best of town and country living to create healthy homes in vibrant communities
- Generous green space linked to the wider natural environment, including a surrounding belt of countryside to prevent sprawl, well connected, biodiverse public parks, and a mix of public and private networks of well-managed, high quality gardens, tree-lined streets and open spaces
- Opportunities for residents to grow their own food, including generous allotments
- Strong local cultural, recreational and shopping facilities in walkable neighbourhoods
- Integrated and accessible low-carbon transport systems – with a series of settlements linked by rapid transport providing a full range of employment opportunities

Garden cities built along these lines will largely exploit existing technologies, an approach already adopted elsewhere. The Zero Carbon Building (ZCB) in Hong Kong, is located at the heart of Kowloon Bay, the upcoming vibrant premier business district. Covering a total area of 14,700 m^2 comprising a 3-storey Zero Carbon Building and a landscape area [26] it both showcases state-of-the art eco-building design and technologies to the construction industry locally and internationally and raises community awareness of low carbon living in Hong Kong. To achieve zero carbon emissions, ZCB adopts an integrated design where the ZCB building and its surrounding woodland must be seen as a single entity. Nevertheless, in addition to the sustainability of future's construction we should also consider the "visuality" and "functionality" of buildings. An intriguing example, Hong Kong Polytechnic University's 15-storey Jockey Club Innovation Tower competed last year [27]. It prospers the diversity, expresses the dynamism and creativity of university life with creating a fascinating turban area. While the tower provides multi-functional usage and is visually attractive, its unique geometry covers less land space than its contenders. The building is a showcase of future high rise construction. Future cities could evolve by progressively adding more buildings following the same principles, each designed for its intended function, residential, offices etc.

The principles incorporated into Hong Kong's ZCB and Jockey Club Innovation Tower can also be seen in Swedish developments. Malmö, Sweden's largest city has undergone economic changes replacing its tradition heavy industry with small and medium size companies. Kjellgren Kaminsky in combination with builders Höllviksnäs Förvaltnings AB, won an open competition for passive houses in April 2009 which have now been built. The buildings have a number of measures for ecological sustainability using a combination of wind, geothermal and solar energy. The original biodiversity of the local area has been maintained and especial attention has been applied to rainwater collection and sewage treatment.

Hammarby Sjöstad (Hammarby Lake City) is a new district in Stockholm built on a previously industrial and harbor area. Hammarby is meant to provide 10,000 apartments for 25 000 inhabitants and occupies 200 hectares of land, close to the city centre. The required environmental impact of the project was limited to no more than half that of the best projects built at the end of the 1990s; in the long term, the energy demand should not exceed 60 kWh/m^2 per year of which not more than 20 kWh/m^2 per year should be electric energy [28]. As with the Malmo development, energy, waste and water systems have been designed for sustainability. A similar development, Beddington Zero Energy Development (BedZED) in London, was completed in 2002 comprises 82 affordable dwellings and commercial site (offices, workspaces) spread on approximately 2500 m^2. The project is a conspicuous example of urban development as it addresses many challenges such as combining workspace with housing, matching with dense urban population, achieving zero carbon standards and increasing comfort level [29].

Japan is also actively developing sustainable "eco" cities, of which a particularly interesting example is the Kitakyushu Eco-Town project [30]. Like the Swedish examples, its development is a response to the decline in highly polluting heavy industry, which contaminated the local, land, sea and air in the 1960s. The target is to reverse this environmental damage by creating a sustainable community through a partnership of the government, commercial organisations and citizens. A key aspect is local recycling of discarded items from bottles to bicycles. Furthermore, all Eco-Town companies must allow their facilities to be inspected by citizens in order to eliminate public distrust and anxiety concerning potential pollution.

The developments described above are based essentially on established technologies following principles that can be applied readily elsewhere to achieve urban sustainability in the near future. They are targeted at relatively modest sized communities typically adjacent or within existing conurbations.

In parallel with these projects, far more ambitious, schemes have been initiated that are creating completely new sustainable cities on virgin ground, especially in states with strong central, governments and with considerable national wealth earned from the sale of fossil fuels. A good example, of a future community is Masdar City in Abu Dhabi (UAE), a project to create the world's first low carbon/zero waste sustainable city [31, 32]. Completely powered by renewable energy, and covering an area of more than seven square kilometres, Masdar City will have the capacity to house 40,000 residents, and host a range of businesses and institutions employing 50,000+ people. But, it is intended to be more than just a demonstration of the practicality of using renewable energy technologies. Masdar City will host a vibrant, innovative, community of academics, researchers, start-up companies and financiers – all focused on developing renewable energy and sustainability technologies.

Another interesting project, Silk City in Kuwait, will be completed in 2023 and will include 30 communities grouped into four main districts; Finance city, Leisure city, Ecological City and the Educational - Cultural city. Silk City will become a new urban centre accommodating 750,000 residents in over 170 thousand residential units. This $132 billion project will create a modern and sustainable oasis, providing hundreds of thousands of jobs and investment opportunities within the world's tallest tower "Burj Mubarak al-Kabir" located in Finance City [33].

King Abdullah Economic City is another representative of the future city concept aiming to have a positive impact on the socio-economic development of Kingdom of Saudi Arabia [34]. The first stage of the city was finished in 2010 and it will be fully completed in 2020. It will consist of several zones enabling industrial, educational, business and residential activities over an area of 173 km^2. Energy/carbon, water, waste, ecology/biodiversity and pollution prevention have been adopted as key parameters in the design of the city [34, 35]. It is also aimed to create up to one million jobs for the youthful population of the country, with where 40 % are under 15 [36].

In response to its considerable environmental problems, a result of its recent industrial growth and need to meet the aspirations of its increasingly wealthy population, China has initiated the construction of many cities based on sustainable designs. In contrast to Europe and Japan, China is able to build on green field sites, an example is Tianjin Eco City in China [37]. Although its development has not been without problems [38] it does appear to be growing at a viable pace [39]. The stated intention is to move one hundred million people into new cities in the next decade, especially in the western part of the country.

Azerbaijan is developing Khazar Islands, a sustainable $100bn city in central Asia on the Caspian Sea, which, when complete in 2020 to 2025 will have 1 m inhabitants. Amenities provided in the city will include; cultural centres and university campuses [40]. The prestigious $2bn Azerbaijan Tower, intended to be the world's tallest, presumably trying to outdo Burj Mubarak al-Kabir. A Formula 1 circuit will also be included. All buildings will be capable of withstanding magnitude 9.0 earthquakes.

While the new cities described above are ambitious they are based on existing or emerging technology and, in principle at least, can be completed within the next decade, designs for far more futuristic cities have also been mooted, siting them underground [41–43], underwater [44], floating on the sea [45, 46] or even in the sky [47, 48].

Arguably the development of the underground city has already started. In London, where real estate is very expensive, wealthy property owners are digging downwards to expand their living space thus avoiding planning regulations. The London Crossrail scheme shows that large underground spaces can be created, but as Harris notes, quoting London's Road Task Force, why not put major roads into new tunnels "…leaving the surface, with its sunlight and trees, for public spaces" [41]? Maybe in localities such as London, where the underlying clay is conducive to excavation, a present day city can evolve into a future city by digging downwards rather growing upwards?

An alternative option for London is Sure Architecture's "Endless (Vertical) City" envisages a 55 storey tower designed for London site which will be a self-contained community complete with areas dedicated to parks [49]. Two ramps wind around the exterior essentially providing "vertical" streets since London does not have the space to accommodate further horizontal streets.

With Japan's lack of building land and susceptibility to earthquakes it is perhaps not surprising that a Japanese company, Shimizu Corporation, has proposed building self-sufficient cities under the sea called "Ocean Spirals" [50–52]. A city with typically 5,000 inhabitants will be contained within a 500 m diameter water-tight sphere, at or near the ocean surface, and connected by a huge spiral to the ocean floor as much as 4000 m below. Aquaculture would be practised in the surrounding sea to produce food sustainably and fresh water would be obtained by desalination. Shimizu claims the first city, costing £16bn, could be ready by 2030, having taken just 5 years to build…and the price of further cities would be reduced as numbers increased.

In contrast to Shimizu, Architect Vincent Callebaut has designed the "Lilypad" city, capable of accommodating 50,000 people floating on the ocean surface [53, 54]. The city integrates a range of renewable energies (solar, thermal, photovoltaic and wind). Intriguingly, since these floating cities float near a coast or travel around the world following the ocean currents, they would avoid the problems of sea level rise resulting from climate change [53, 54].

The Venus Project, proposed by US inventor, Jacque Fresco, is another circular city comprising a central dome containing the cybernetic systems that maintain core automated city functions [55, 56]. Fresco goes way beyond developing a sustainable city. He wishes to create an utopian, technological civilisation without money that avoids the ills of all previous forms of economic and political systems…capitalism, government, fascism, communism, socialism and democracy. Fresco considers that by creating the ideal environment for humans it will naturally eliminating violence, greed, and the inequalities that presently afflict us. His philosophy seems to be in a tradition that can be traced back to Plato and Thomas More. The ideas espoused are beguiling, but are they achievable? Could they survive in a world where the pursuit of power and wealth is the prime objective of some individuals, whether ostensibly justified by nationalism, religious belief, or political creed? Indeed, to fully buy into the Venus Project requires a strong belief in its philosophy.

Even more fanciful than London's "endless City" and inspired by the form of the lotus flower [48], is Tsvetan Toshkov's, "'City in the sky' which he claims is a concept embodying an imaginary tranquil oasis above the mega-developed and polluted city, where one can escape from the everyday noise and worries." Although a delightful exercise in creating a utopia away from the strains of modern city life, the engineering stresses within the proposed structure raise questions about its practicality.

Despite the ambitious, indeed grandiose, designs of future cities requiring considerable planning, rapid urban renewal may become vital in response to natural disasters notably earthquakes and hurricanes. While nobody would wish such misfortunate on any city with the human tragedies engendered, the opportunity presented to rebuild a devastated city to both improve its sustainability and to reduce the risk of future disaster cannot be overlooked, not least as an honour to those who have suffered. Two examples are the Wenchuan and Qingchuan districts of Sichuan Province, severely damaged by the 2008 earthquake, which are now in the reconstruction process.

These areas suffered because buildings were not earthquake resistant. Reconstruction has been difficult and a large number of temporary shelters that are neither durable nor thermally comfortable have been built in an attempt to meet the urgent needs of those affected. A research team led by Prof. Zhu Jingxiang of the School of Architecture at The Chinese University of Hong Kong (CUHK) has developed an integrated light-structure system for the reconstruction of New Bud Primary School at Xiasi village in Sichuan's Jiange County [57]. With the support of the Hong Kong Dragon Culture Charity Fund and the CUHK New Asia Sichuan Redevelopment Fund, the new school was completed and in operation in just two weeks. The building is safe and durable, and the cost of construction is low. It also looks attractive and features good thermal performance and a high energy-saving capacity. Maybe inspired, elegant, but eminently practical designs to rebuild shattered communities rapidly and sustainably will be more important and helpful to humanity than some of the grandiose schemes presently on drawing boards?

Building future cities

Of course, new cities, based on existing modern technology, are already being designed and built. China is responsible for about half of global construction work and will build 400 new cities and towns within the next 20 years [58]. China is also moving rapidly towards implementing a low carbon economy and have recently selected 5 provinces and 8 cities for low carbon demonstration [58, 59]. However, city design and technology must continue to develop, not least because more than 80 % of the world's Global Warming Potential (GWP) is created in cities [60, 61] and by 2050 66 % of the world's population will be urban [62]. Accordingly, advanced construction methods and materials will be needed for sustainability in future's cities. Robotic/digital design based technologies coupled with 3D printing of prefabricated modules will reduce construction times, minimise energy consumption and eliminate wasted material, all contributing to lower costs [63, 64]. This technology will be an important step for redesign/reconstruction of cities towards sustainability. Basically with the 3D printing, robotic arms with three axis freedom of movement can construct the building, based on the architectural design, which is coded into the controller of the 3D printer. 3D printed buildings provide aesthetics while minimizing the constructional defects which is generally an issue in conventional buildings [65, 66].

A return to timber as a major building material is especially attractive since each cubic meter of wood can store half tonne of carbon [67]. Can we make buildings that work like trees and cities like forests? New cities will exploit new materials that will deliver greater functionality. For example nano-materials already offer opportunities for advances in sensors [68] and smart polymers [69]. However, it is just as important that future cities are constructed from materials that are completely recyclable and sustainable [70]. Where virgin feedstock is required it must be taken from renewable sources, which in many instances will be biomass-based [71]. For health and safety reasons manufacturing processes are currently located at distances from major conurbations. In the future processes are required that are low hazard and can be integrated into cities, close to workers homes. The newly emergent disciplines of Green Chemistry and Green Engineering are addressing the development of future manufacturing industry [72].

With buildings being responsible for almost half of all energy consumption and carbon emissions in Europe, new build properties are becoming much more energy efficient and their environmental footprint is being reduced [73, 74].

The Energy Performance of Buildings Directive, EPBD (EU, 2010) requires that all new buildings shall be "nearly zero energy buildings" (nZEB) by the end of 2020 [75]. EPBD is not limited to new buildings, but also covers retrofit of existing buildings because these constitute the majority. Accordingly, building materials are in the spotlight as they have a large influence on building energy consumption, carbon emissions, urban warming and comfort level. Solid wood has been used as a building material for thousands of years, appreciated for being a lightweight, easy reusable and naturally regrown resource (See: Fig. 4). Today, "wooden construction" is innovative and on the rise: timber is again regarded as an ideal green building material [76–78]. Recently a 30 storey tower, has been designed by Michael Green for Vancouver, Canada. Once built, it will be the tallest wooden construction, overtaking its competitors Forte Building, Melbourne and Stadthaus, London [78].

Since timber is one of the few materials that has the capacity to store carbon in large quantities over a long period of time, some of the historically negative environmental impact of urban development and construction could be avoided. As seen in Fig. 5, while 1 kg wood can store 9 kg CO_2, the rest of building construction materials positively contribute to the CO_2 emissions, particularly the aluminium has a significant footprint on the environment by releasing 27 kg CO_2 per kg [79, 80].

Nanotechnology is also expected to have a wide range of usage in future's buildings. In the last decade this technology has been used in the building industry to improve the structural, mechanical, hygienic, aesthetic and energy-related properties of building materials. Nanomaterials can be either added to the building materials or used as coatings. For instance applying nano scale coatings of titanium dioxide breaks down the dirt as and provides a self-cleaning effect when it is applied to windows, frame, glazing or roof tiles [81, 82].

Feeding future cities

According to WHO 50 percent of the 7 bn global population is currently living in cities requiring a land area for farming equivalent to half of South America to produce their food [83]. In the next 40 years there will be 3 billion more people [84, 85] to feed implying 50 % more food production [83]. Since 80 % of the world's population is predicted to be living in cities by 2050, seemingly generating a conflict between using land for agriculture and for cities if the extra food production is obtained via traditional agriculture. But the problem of feeding the inhabitants in future cities may be less severe than we imagine. Historically, some cities at least integrated agriculture into their structure… Ankor Wat and Tenochtitian were mentioned above. During WW1 and WW2 the gardens and spare ground within British and German cities were turned over to the growing vegetables. Even Einstein cultivated an allotment in WW1, although he was reprimanded for it being untidy. Even the USA increased its food production in WW2 by promoting victory gardens. With the collapse of the Soviet Union in 1990, Cuba lost its supplies of fertilizers and agrichemicals precipitating a crisis in food production. To survive, Cubans turned to intensive urban agriculture to augment their food supplies, an activity which continues to this day. Ironically, when people are restricted to a diet of smaller amounts of freshly grown local food less in quantity than previously, their general level of health improves, an effect clearly evident in both 1940s Britain and 1990s Cuba. In a

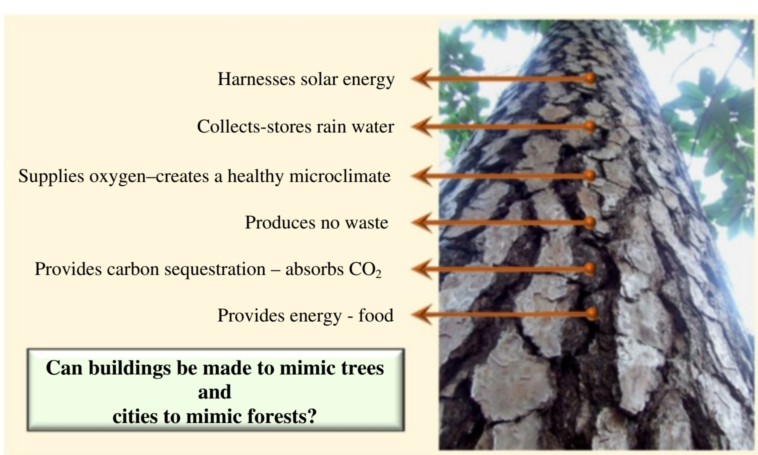

Fig. 4 Benefits of using wood as building construction material. Legend - Wood is the only material with a negative CO_2 balance; each cubic metre of wood sequestrates on average 0.8 to 0.9 tonnes CO_2 [79, 80]. Building with wood could play a vital role in reducing air pollution and global warming. Being a natural material it will not produce any waste and can be recycled. Wood can also be an energy source for future cities

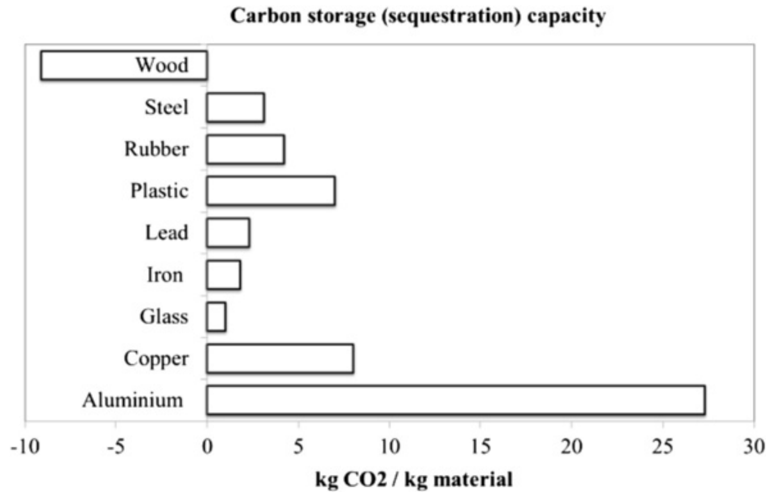

Fig. 5 Carbon storage capacity of building construction materials [79, 80]

recent paper Thebo et al. suggest, based on satellite data, that urban agriculture already contributes significantly to the global food supply since an area within 20 km of cities equivalent to the 28 EU states combined is already being used for agricultural activities [86]. The detailed analysis is summarised in Fig. 6;

Martellozzo et al. suggest the potential for vegetable growing within urban areas would require roughly one third of the total global urban area to meet the global vegetable consumption of urban dwellers. But the urban area available and suitable for urban agriculture varies considerably depending upon the nature of the agriculture performed. They reluctantly conclude that the space required is regrettably the highest where need is greatest, i.e., in more food insecure countries. They note that smaller urban areas offer the most potential as regards physical space [87].

In the developed world urban food growing is becoming popular perhaps for three reasons: firstly by the middle classes the appreciation that urban food cultivation can re-establish the link between food production and consumption, especially for children, encouraging them to adopt a more healthy diet; to supply free, fresh food for those in poverty and perhaps already relying upon food banks; and ironically for high end restaurants. One example of such community organisations world-wide is York Edible [88] in the city of York, UK.

To reduce their environmental impact future urban dwellers will increasingly grow food within, or at least in the immediate hinterlands, of their cities to avoid the CO_2 emissions associated with food transportation especially over transcontinental distances [89]. It is estimated that each 1 Calorie of consumed food uses currently 10 Calories of oil [90–92]. But where ground is at a premium, food production might be integrated into future cities by 'Vertical Farming', i.e. multi-tier city farms in the form of glass protected skyscrapers or high rise towers that grow the maximum amount of on a minimum land area [93–95]. Although one dedicated vertical farm could feed up to 50,000 people [96], it is still likely that it will be beneficial for all buildings in future to have space reserved for food production. With the recent developments in photovoltaic (PV) technology it will be also possible to design vertical farms self-sufficient and completely sustainable. The primary energy consumption of vertical farms is for lighting (creating mimic sunlight) and water pumping for irrigation. Al-Chalabi conducted a study evaluating the sustainability of skyscrapers for vertical farming with different building dimensions as given in Table 2. According to the study results, for the vertical farms with a floor area less than 500 m^2, the available space on roof/façade is enough to install required the required number of PV panels. But once the floor area exceeds 500 m^2 the space on roof/façade is insufficient [97].

In March 2014, the world largest vertical farm was opened in Michigan (USA) with 17 million plants in plant racks using LED light to mimic sunlight [98, 99]. The American National League of Cities is promoting urban agriculture [100] as a part of its remit to make cities more sustainable.

The most ambitious schemes for vertical farms will take a long time to realise, if ever. But some more modest examples already exist, for example in Singapore [101, 102], Sky Greens has constructed a four storey building using traditional growing systems comprising soil based potted plants on a series of conveyor belts which migrate the plants near the windows maybe once or twice an hour so that every plant gets same amount of sunlight during the day. The technology increases food production by a factor of ten compared to that of traditional farming on an equal land area [102]. Other vertical farms have been built in Korea, Japan, the USA and Sweden [98–100, 102]. Singapore, one

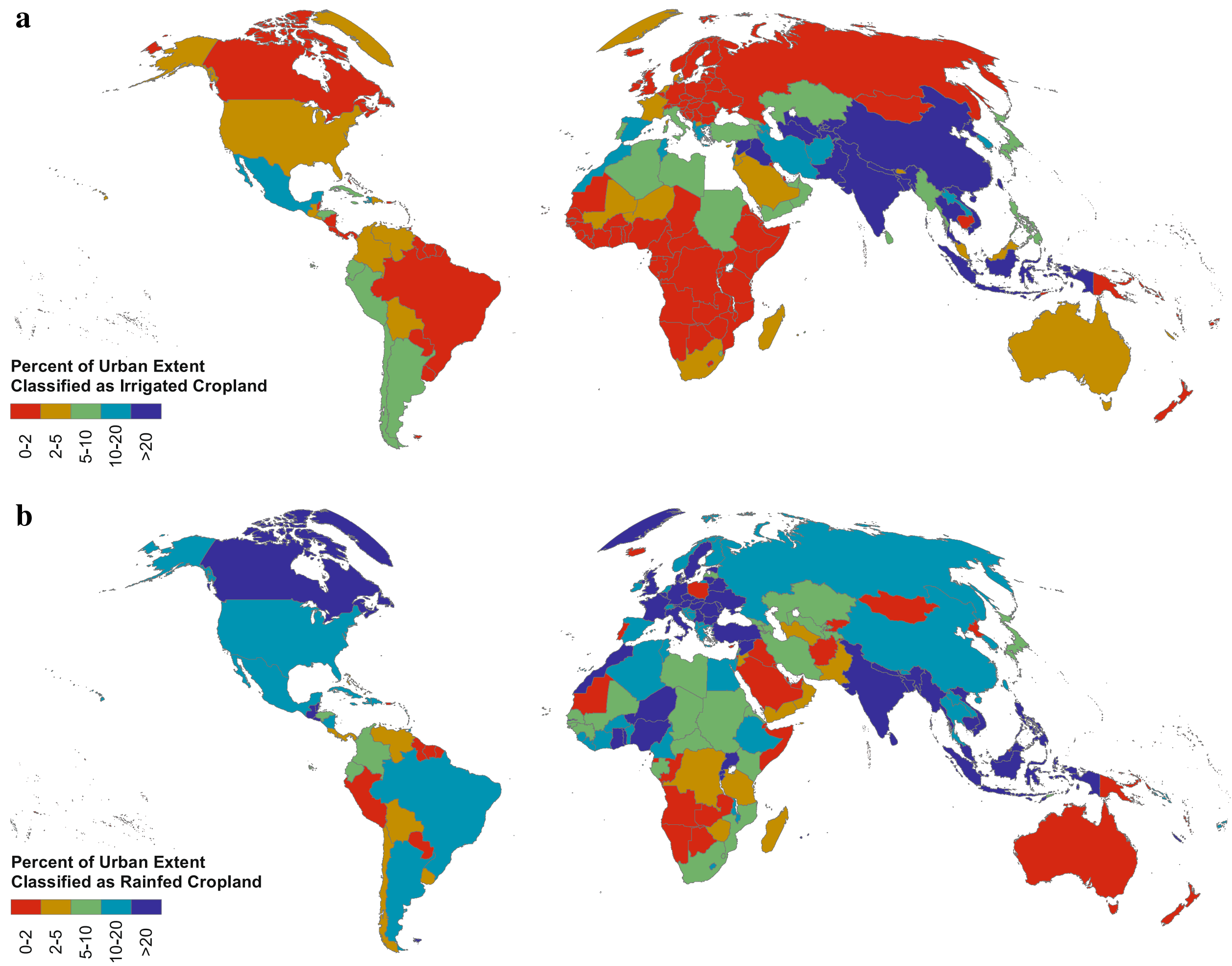

Fig. 6 Schematic illustration of allocated urban area for irrigated and rainfed croplands [86]. Percent of urban area classified as (**a**) irrigated cropland, (**b**) rainfed cropland by country. Legend Proportion of irrigated cropland tend to be higher in regions having larger urban extend area used for irrigated cropland. However proportion of rainfed cropland is more dependent on regional climate patterns

of the most densely populated countries, is considering a futuristic "floating vertical farm" designed by Forward Thinking Lab of Barcelona [103]. The system basically consists of looping towers that could float in local harbours, providing new space for year-round crops. The concept is inspired in part by floating fish farms that have been in use locally since the 1930s [103].

The flip side of producing and consuming food is that it creates human waste that must be treated to avoid pollution. Although human faeces and urine have been used

Table 2 Optimisation model for the vertical farm. Adapted from [97]

Dimensions of building		Energy demand (one month timeline)				Energy supply	Feasible
Length/width (m)	Area/floor(m^2)	Water pumping required (kWh)	Light required (kWh)	Total required (kWh)	PV required (number of panels)	PV available on roof/façade (number of panels)	PV available-PV required
10	100	148	0	148	4	593	Yes
20	400	591	0	591	15	1289	Yes
22.5	506	748	57946	58694	1398	1479	Yes
25	625	923	137388	138311	3294	1675	No
28	784	1158	257393	258551	6165	1920	No
30	900	1329	352350	353679	8421	2088	No

historically as fertiliser thus creating an "eco-cycle" (Fig. 7), it has long been discouraged in developed countries because of food contamination by pathogens. This especially applies to uncooked foods such as salads. Progressive build-up of toxic, heavy metals in the soil and thus plants is also a long term problem. But merely treating sewage and discharging the resulting effluent to rivers or the sea loses valuable nutrients, notably phosphorus, and also nitrogen and potassium, which have to be replaced from unsustainable sources. Vancouver based, Ostara has developed the "Pearl Process®" that recovers phosphorus and nitrogen plus magnesium from waste water to produce a slow release fertiliser called "Crystal Green®", which has a low heavy metal content [104]. The first European plant has recently been installed in Slough UK to treat water from a local industrial estate. Although Crystal Green is presently sold for conventional agriculture, technology of this type will be essential for sustainable urban agriculture. Energy input, required to operate the process, can potentially be obtained from renewable sources, especially solar [105].

Transport for future cities

To overcome rising traffic problems, cities should be compactly structured with improved accessibility, and have a well-designed transport network.

In future cities effective transportation will play a key role. For the health and well-being of citizens walking and cycling between their homes, workplaces, shops and other locations is already being encouraged. Undoubtedly these self-propelled systems will be integrated into future cities, avoiding the modern day perils of mixing pedestrians, cyclists and powered vehicles. For distances and occasions where self-propelled travel is impractical then future cities will need to strike a balance between mass public transport (buses and trams), individually-hired vehicles (taxis and rental cars) and individually owned vehicles. Various technologies already in development will impinge upon the choices made, such as self-driving vehicles [106, 107], electric vehicles [108, 109] and Aero-Mobil [110]. Aero-Mobil is a flying car that integrates existing infrastructure used for automobiles and planes. As a car it can fit into any standard parking space,

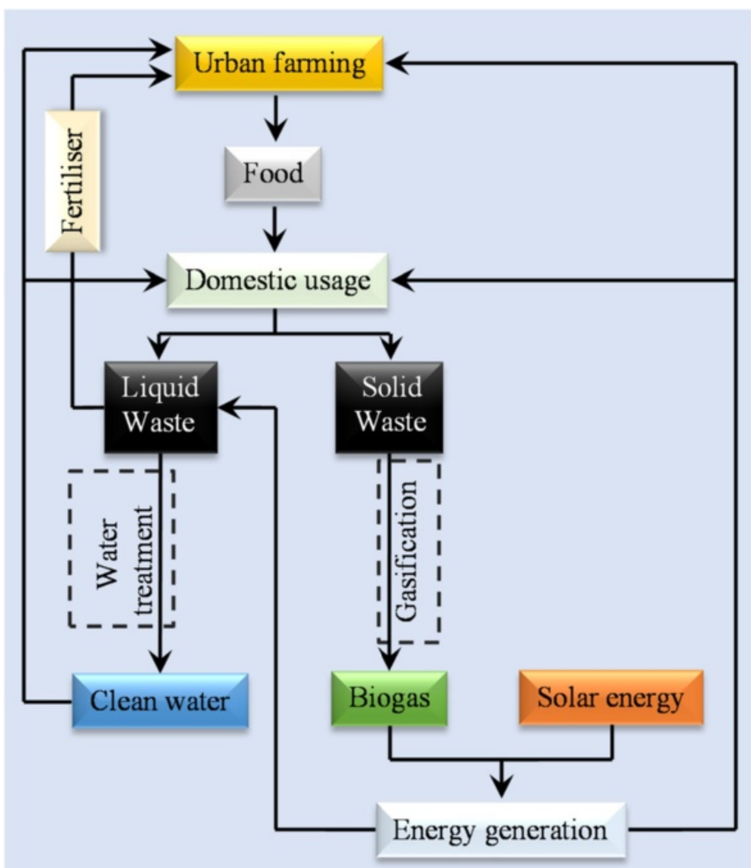

Fig. 7 Eco-Cycle describing the recycling of solid waste and sewage for food, water and energy production for sustainability of future cities. Adapted from [105]. Legend Advanced water treatment systems for clean water production and advanced systems for gasification of solid waste for energy generation could allow considerable amount of water and energy savings. These could be reused for domestic needs and urban farming for food production. Additionally required fertilizer for urban farming can also be produced from sewage with processes such as "Pearl Process"

uses regular gasoline, and can be used in road traffic just like any other car. As a plane it can use any airport in the world, but can also take off and land using any grass strip or paved surface just a few hundred meters long. It is now finalised and has been in regular flight-testing program in real flight conditions since October 2014. The Aero-Mobil is built from advanced composite material includes its body shell, wings, and wheels. According to company authorities the final product will include all the standard avionics and, an autopilot plus an advanced parachute deployment system [110].

Undoubtedly safety will be improved over current transport systems, but a serious debate is required concerning citizens' freedom to own their vehicles against potentially more energy efficient mass transport. The driverless, for-hire vehicle summoned by an app may find increasing acceptance. At present road vehicles are dual purpose, being used for both modes but in the future a distinction may be drawn between *intra*-city transport and *inter*-city transport [111, 112]. For long distances the speeds of trains may increase so journey times rival those of intercity aircraft, but operate with superior energy efficiency, for example maglev trains [113, 114] exploiting superconductivity and the "Aero-train" that is part train and part aircraft [115].

Traffic and transportation are growing problems for all cities. In Europe, people are wasting 10 to 60 [116] hours in traffic jams each year, while their vehicles are contributing significantly to global warming by emitting carbon dioxide emissions and to air pollution by emitting nitrogen oxides and carbon particles. Therefore traffic management and monitoring systems are currently already being applied in many large cities and people are strongly encouraged to use public transport instead of personal vehicles. Even though some steps have been taken more radical, innovative will be needed. Perhaps "futuristic" solutions can no longer be viewed as engineers' fantasies but essential to avoid increasing urban transport problems.

Chinese engineers have allowed a Hongqi Q3 car to navigated itself through traffic to a destination 286 km away guided by cameras and sensors [117]. It is clear that computers can be safer drivers than human beings. They can react quicker, they can look in all directions at once and they don't get distracted. They won't speed or cut people up. Principally, self-driving cars will be connected with a wireless network similar to the internet or telephone network and all cars will be travelling on major roads under control of satellite and roadside control systems [118]. A traffic jam will be predicted before it even happens by using roadside sensors, GPS and other advanced software.

An alternate innovative design for future transport is the Aero-train which is partly train and partly aircraft. The vehicle is designed with wings and flies on an air cushion along a concrete track using wing and ground effects. This minimises the drag effect allowing the aero-train to consume less energy whilst reaching higher speeds than the conventional trains [115].

Another imaginative idea, first proposed by Robert M. Salter in the 1970s, is the evacuated tube transport (ETT) where a vehicle occurs in a vacuum to eliminate air resistance and friction, [119]. The ETT system envisions superconducting maglev trains operating at speeds of up to 6,500 km/h (4,039 mph) on international trips - that's New York to Beijing in two hours! Although the proponents say that ETT could be 50 times more efficient than electric cars or trains it is only a concept that is the subject of ongoing research [120]. But the achievement of ETT would revolutionise future long distance transportation.

Administering future cities

According to the UN report 70 % of the world's population will live in urban areas by 2050 [61, 62] with the number of cities expected to exceed 2000 by 2030, compared to 1551 in 2010 [121]. Whilst there are 43 'large cities' with populations between 5 and 10 million in 2014, there are expected to be 63 by 2030 [62]. The UN estimates that there will be more than 40 mega-cities worldwide by 2030, each with a population of at least 10 million, compared to 28 today. It is projected that Delhi, Shanghai and Tokyo will each have more than 30 million people by 2030, and will be the world's largest urban agglomerations [62]. This massive global growth of urban areas will requires developments in administrative systems to ensure that technological advances described in previous sections truly deliver improved living conditions for all urban dwellers. Key challenges for future cities will be productivity, sustainability, liveability and good governance [122–125] as summarized in Table 3.

Although the well-established scientific basis for global warming is well established, its full impact appears to be several decades in the future, action is required now to ameliorate its effects by identifying, prioritizing, and structuring new design and managerial tools to improve urban environmental and fiscal sustainability [126]. Despite the vociferous assertions of those denying man-made global warming, the ill effects of "local warming", known as the "urban heat island effect" (UHIE), are already manifest in large cities, especially in the tropics and serves as early warning of what is likely to happen worldwide as global warming becomes more pronounced. UHIE refers to the urban temperature being higher than that of the surrounding countryside, 3 K being not a typical, a combination of solar heat absorption by buildings, roads etc., heat emitted by vehicles, and the conversion of electrical to thermal energy, for example by air conditioners.

The UHIE does not just cause discomfort for urban inhabitants, it is also a killer. Various studies of temperature related excess mortality using historical data have shown that during heat waves above a threshold temperature

Table 3 Challenges for future cities and desired objectives-principles to overcome these challenges [122–125]

Challenges	Objectives	Principles
Productivity	○ Improve labour and capital productivity	Efficiency Value for money Innovation Adaptability Resilience Equity Affordability Subsidiarity Integration Engagement
	○ Integrate land use and infrastructure	
	○ Improve the efficiency of urban infrastructure	
Sustainability	○ Protect and sustain our nature land built environments	
	○ Reduce greenhouse gas emissions and improve air quality	
	○ Manage our resources sustainably	
	○ Increase resilience to climate change, emergency events and natural hazards	
Liveability	○ Facilitate the supply of appropriate mixed income housing	
	○ Support affordable living choices	
	○ Improve accessibility and reduce dependency on private vehicles	
	○ Support community wellbeing	
Good Governance	○ Improve the planning and management of our cities	
	○ Streamline administrative processes	
	○ Evaluate progress	

deaths increase significantly with each further degree rise. Not surprisingly, the young, old and those with serious medical conditions, a most vulnerable [127].

If a city experiences a heat wave of lasting longer than 5 days the UHIE results in excess mortality that raises steeply with every extra degree of excess temperature during night time; the correlation is weaker with the daytime temperature. Not surprisingly, the young, the old and those with existing medical conditions are most at risk.

Mitigation technologies such as increasing green urban space and biodiversity, use of reflective materials, decrease of anthropogenic heat levels and use of low temperature natural sinks (such as ground or water bodies) aiming to counter the impact of the phenomenon are rapidly being developed and applied in real projects [128]. Rehan provided a detailed framework, including several measures that will diminish the accumulation of heat in urban areas and mitigate their UHIE by a set of planning actions as a strategy to cool the cities. The framework is given in Fig. 8 [129]. Richer urbanites can in principal, offset the effects of the UHIE merely by turning up their air conditioning or installing more powerful units. But such would be socially reprehensible since it would increase urban temperatures further to the disadvantage of poor who cannot afford a/c or the power to run it. Nevertheless, to protect the vulnerable it may be necessary to build air conditioned refuges where they can be sent when local temperatures are high.

Administrators are already aware of the need to incorporating UHIE mitigation as cities are further developed and is required in temperate regions as well as the topics. For example Public Health England has recently published an excellent guide the adverse effects of high temperatures and methods to combat them, both short and long term [130].

Although excess mortality caused by the UHIE is occurring now, it will be exacerbated by the rise in global temperatures projected by the Intergovernmental Panel on Climate Change (IPCC) [128, 131]. Those who argue strongly that man-made global is a myth and therefore nothing needs to be done to mitigate it, must face the consequence if the world follows their lead and they are wrong people, especially the poor and vulnerable will die. The adverse effect of increasing temperatures is based on sound research and historical data. It is not a theory derived from a computer model. Planning and building "cool" cities must be a primary objective of administrations now to minimise deaths.

In large cities excess mortality from attributable to high temperatures is exacerbated by air pollution, notably NO_x from internal combustion engines that ozone produced by the sunlight-induced reaction of oxygen with unburnt hydrocarbons. Indeed, separating excess urban mortality arising from pollution and high temperatures is problematical. Fortunately mitigations for both tend to be the same…for example by reducing fossil fuel combustion to supply electric power by increasing renewables, reducing the number of internal combustion engine vehicles coupled with the provision of better public transport and "greening" cities by planting more vegetation capable of both cooling the air and absorbing airborne pollutants.

Originally, "green" infrastructure was identified with parkland, forests, wetlands, greenbelts, or floodways in and around cities that provided improved quality of life or "ecosystem services" such as water filtration and flood control [132, 133]. Now, green infrastructure is more often related to environmental or sustainability goals that cities are trying to achieve through a mix of natural approaches. Examples of "green" infrastructure and technological practices include green [134], blue, and white roofs [132] (See: Fig. 9); hard and soft permeable surfaces; green alleys and streets; urban forestry; green open spaces such as parks and wetlands; and adapting buildings to better cope with floods and coastal storm surges [132].

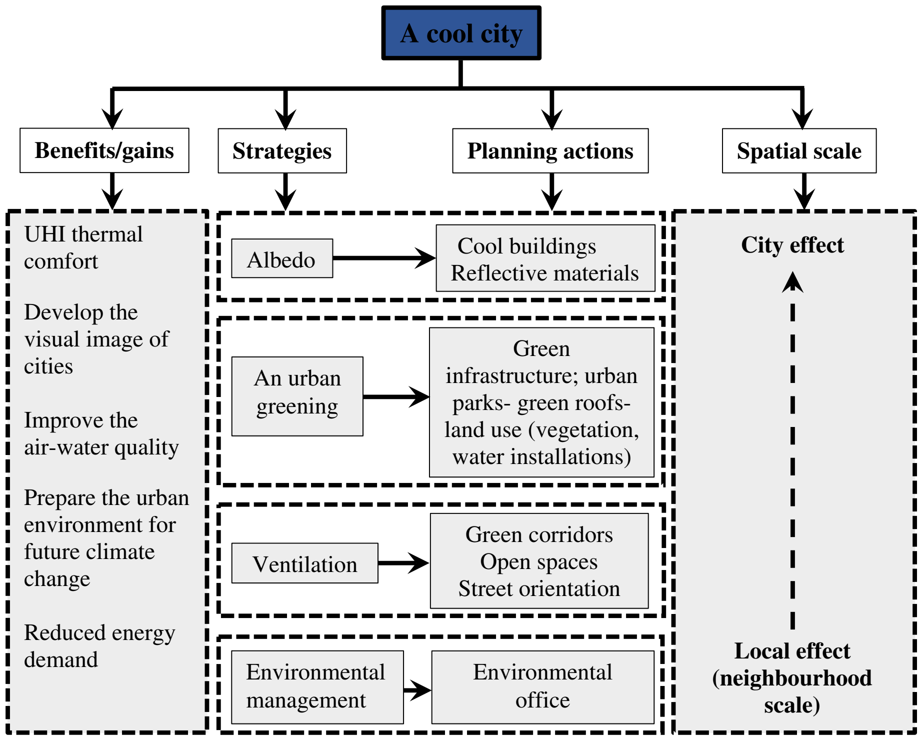

Fig. 8 Cool city- Framework [129]

The climate adaptation benefits of green infrastructure are generally related to its ability to moderate the expected increases in extreme precipitation or temperature. Benefits include better management of storm-water runoff, lowering incidents of combined storm and sewer overflows (CSOs), water capture and conservation, flood prevention, accommodation of natural hazards (e.g., relocating out of floodplains), reduced ambient temperatures and urban heat island (UHI) effects, and defense against sea level rise (with potential of storm-surge protection measures). The U.S. Environmental Protection Agency (EPA) has also identified green infrastructure as a contributor to improving human

Fig. 9 A view of an urban green roof in Chicago, USA [134]

health and air quality, lowering energy demand, reducing capital cost savings, increasing carbon storage, expanding wildlife habitat and recreational space, and even increasing land-values by up to 30 % [132, 135]

Green infrastructure (GI) in urban areas can ameliorate the warming effects of climate change and the UHIE. In a study performed by Gill et al. (2007) [136, 137] it is found that that increasing the current area of GI in Greater Manchester, UK by 10 % (in areas with little or no green cover) would result in a cooling by up to 2.5 ^{o} C under the high emissions scenarios based on UKCP02 predictions. The potential benefits of increased green infrastructure/green space on reducing UHIE are presented below:

- Trees and shrubs provide protection from both heat and UV radiation by direct shading (both of buildings and outdoor spaces).
- Evapotranspiration reduces the temperature in the area around vegetation by converting solar radiation to latent heat.
- Lower temperatures caused by both evapotranspiration and direct shading lead to a reduction in the amount of heat absorbed (and therefore emitted) by low albedo man-made urban surfaces [136, 138].

These changes can only be achieved by a city administration that has both the appropriate legal power and the will to serve all its city's inhabitants, the poor as well as the rich.

Much of what has been discussed above has ignored the differing sizes of conurbations.

Cities face different impacts, depending upon their sizes and levels of development. Small cities of upper income nations are facing with population decline as a result of the migration to larger cities for better job opportunities and higher life standards. Diminishing manpower makes it difficult for small cities to compete globally in terms of economy and productivity. On the other hand large cities in developed world are facing with the impacts of aging infrastructure and population. Increasing population creates inequality and social cohesion inside the cities while job opportunities become more competitive [125].

In contrast to developed nations, small cities in developing countries are faced with the impacts of weak economies and weak urban governance. Due to their inadequate infrastructure and buildings, such cities lack the resilience to survive natural disasters such as earthquake or flood is very low. This Survival is threatened and in many cases many people are forced to vacate their homes (See Fig. 10b). Even large cities in the developing world with inadequate/insufficient transport as well as poor housing stock, are threatened by demographic challenges resulting in social and economical inequality. Environmental pollution is probably the most significant problem facing these cities, a result of the rapid industrialisation. But the latter potentially creates the wealth that can

	Upper Income Nations	Developing World
Small Cities	○ Population decline ○ Competing globally ○ Economic restructuring	○ Weak economies ○ Inadequate infrastructure for provision of basic public services ○ Weak urban governance
Large Cities	○ Ageing infrastructure & population ○ Inequality and social cohesion ○ Increasing competition for global leadership	○ Inadequate transport infrastructure and severe congestion ○ Population housing and slums ○ Demographic challenges ○ Environmental problems ○ Social and economic inequality

Fig. 10 Impacts of global urbanization; (**a**) Flue gas emitting from a factory polluting the air in an urban area, (**b**) People vacating their houses after a flood disaster. Table represents the specific impacts of global urbanization depending on the size and development level of a city

enable developing world cities to overcome their growing pains provided it is harnessed for benefit of all and is not siphoned off by corruption.

In many cities of China (See Fig. 10a) and India, environmental pollution, particularly $P.M_{2.5}$ (e.g. oil smoke, fly ash, cement dust) level is sharply rising and threatening the human health as $P.M_{2.5}$ particles have the ability to penetrate deep into the lungs and can cause severe health problems [139].

The severe impacts of rapid urbanisation can be ameliorated by applying creative design to infrastructure. Ecosystems like multifunctional units will provide several uses rather than a single functionality thereby saving energy, time and cost. For instance garden plots can serve as water management system while providing food for citizens. Similarly multifunctional buildings could save time for people while allowing efficient use of land [140].

Significant advances in computer simulation provided tools that enable us to evaluate current conditions and requirements thus modelling future scenarios. This phenomenon will have increasing importance in future cities to monitor existing conditions for efficient use of capital and natural resources or controlling traffic flow through wireless sensor networks [141–143]. In addition it will allow modifying energy usage or household waste of urban dwellings with real time feedback [144–147]. South Korea has already put this technology into practice in city of Songdo, where traffic, waste and energy usage are monitored [140]. Similarly in Rio de Janeiro there is a high-tech centre where public safety responses to natural disasters or building collapses are quickly identified [146, 147]. The recent earthquake in Nepal demonstrated that, this kind of technological centre could save many lives with timely intervention during disasters.

Technically, highly automated management systems are very attractive, but they have potential downsides. The amassing of large amounts of data about individuals' daily lives is already creating grave concern, both via the internet and CCTV. Increasing data collection could offer the potential for city authorities to exercise greater control over citizen's lives. Technology must be tempered by democratic safeguards if individual liberties are not to be infringed. The vulnerability of a highly networked city to a physical or a cyber- attack on data centres must be minimised. A fascinating concept currently being pursued is the adaption of the "block-chain" algorithm underlying "bitcoin" to the administration of organisations to increase transparency and to minimise corruption [148].

For example recently "Ethereum" launched is a block-chain platform that allows secure systems to be developed with transactions permanently and transparently recorded [149].

Large corporations already experimenting Ethereum, include UBS and Barclays. "BoardRoom" is a block-chain dapp (distributed app) founded by Dobson who claims that it can be used to run large organisations by "collaborative decision making" [150].

These developments could potentially be just important to the operation of modern cities as the new engineering technologies.

Socio - economic development and prosperity of future cities

Emerging cities should be where human beings find satisfaction of basic needs and essential public goods. Where various products can be found in sufficiency and their utility enjoyed. Future cities should also be the habitats where ambitions, aspirations and other immaterial aspects of life are realized, providing contentment and happiness and increasing the prospects of individual and collective well-being. However in many developing cities, prosperity is absent or restricted to some groups or only enjoyed in some parts of the city [6].

Low purchase power contrarily increasing expenses could socioeconomically pressurize individuals and minimize their social subsistence. This situation will turn citizens from productive and creative individuals to the ones just trying to survive. "Liveable" cities should support affordable living choices, provide citizens options to have a social status and life conditions independent than their income. Cities also should be compact structured with improved accessibility, they should include natural habitats allowing biodiversity and socialisation of individuals and should have a well-designed transport network which will eliminate the need for private vehicles to overcome the rising traffic problem in growing cities. Besides they should offer a profusion of public goods, develop actions/policies for a sustainable use and more importantly should enable equitable access to 'commons'[3] in order to ensure well-being of citizens.

The future urban configurations should concentrate on efficient use of resources and opportunities that could help to achieve prosperity and citizen well-being in five dimensions as defined below and illustrated in Fig. 11;

- Contribute to economic growth through productivity, generating the income and employment that afford adequate living standards for the whole population.
- Deploy the infrastructure, physical assets and amenities – adequate water, sanitation, power supply, road network, information and communications technology etc. – required to sustain both the population and the economy.
- Provide the social services – education, health, recreation, safety and security etc. – required for improved living standards, enabling the population

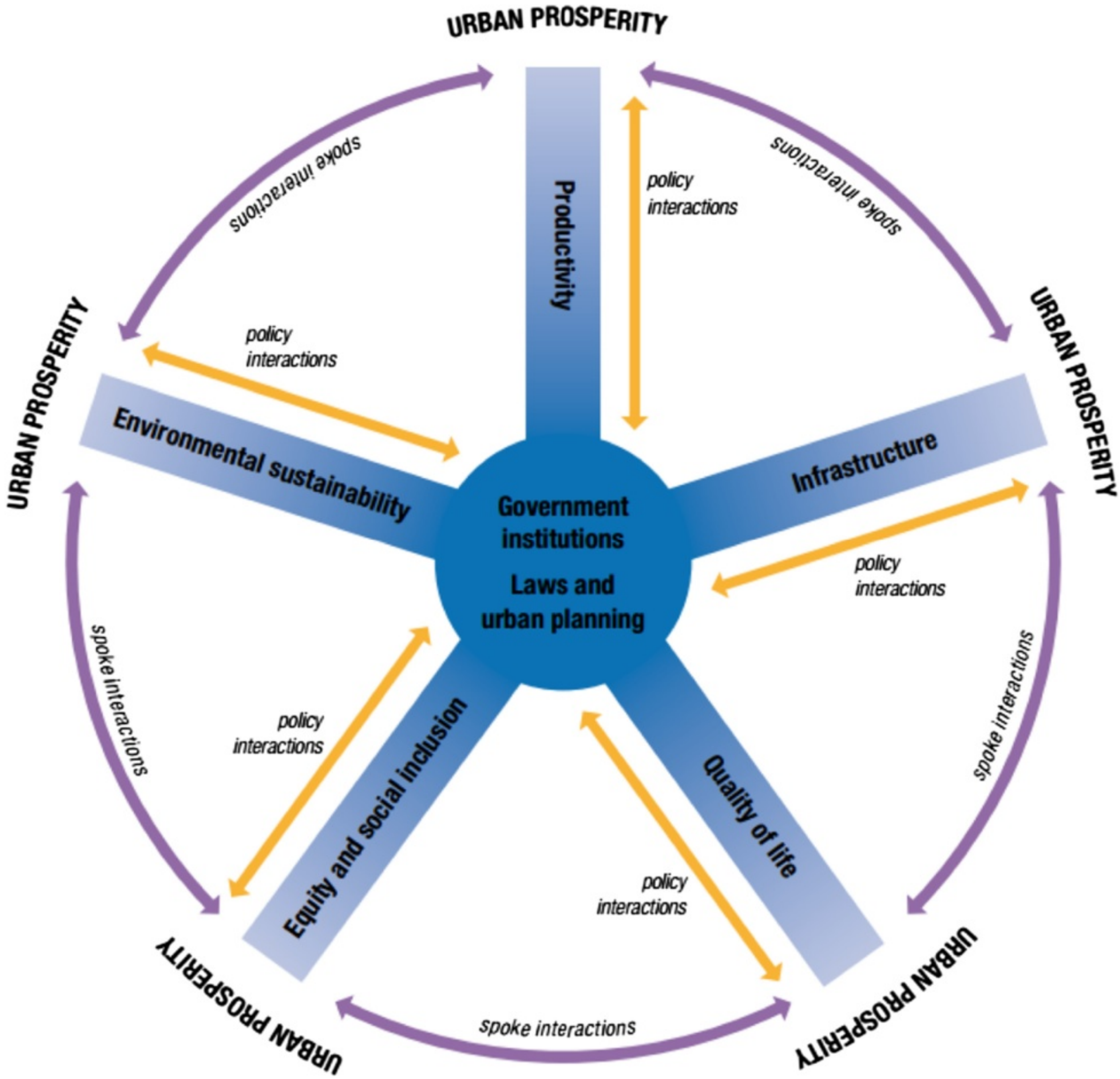

Fig. 11 Wheel of urban prosperity [6]

to maximize individual potential and lead fulfilling lives.

- Minimize poverty, inequalities and segments of the population live in abject poverty and deprivation.
- Protect the environment and preserve the natural assets for the sake of sustainable urbanization.

The past few decades have witnessed a notable surge in economic growth, but one which has been accompanied by an equally daunting degree of inequity under various forms, with wider income gaps and deepening poverty in many cities across the world. Economic inequality is seriously detrimental to the equitable distribution among individuals of opportunities to pursue a life of their choosing and be spared from extreme deprivation in outcomes. According to recent reports, income gaps between rich and poor are expanding in both developed and developing countries [6, 151]. In OECD countries, inequalities are as steep as they have been for over 30 years. In advanced economies, the average income of the richest 10 % of the population is about nine times higher than that of the poorest 10 %. In Europe's Nordic countries, the average is a multiple of six but growing, compared with multiples of 10 in Italy, Korea and the United Kingdom [151], and up to 14 in Israel, Turkey and the United States [6].

Cities must realize that equity has a significant impact on socio-economic performance, since the greater the degree of equity, the greater the chances of a wider, more efficient use of available resources, including skills and creative talent [152] Urban prosperity thrives on equity, which involves reduction in barriers on individual/ collective potential, expansion of opportunities, and strengthening of human agency [6, 153] and civic engagement. Cities generate wealth, but the problem is the unequal distribution of it. Despite considerable increases in productivity (e.g. GDP per capita) along with reductions in extreme poverty, inequality as a whole is growing in most parts of the world – a process that undermines urban life quality [154]. In many cities, the population and local experts concur that inequalities are becoming steeper which could be a threat for emerging cities in terms of their sustainability and well-being of citizens.

Conclusions

The "Future Cities" topic employs a multidisciplinary approach to address the urban development challenges facing emerging cities. This can integrate environmental technologies, comprehensive urban development, fiscal sustainability and good governance, to provide emerging cities with a set of tools in order to improve the quality of life globally.

New-born babies in developed countries are projected to have a life expectancy of 80+ years [155], with the majority living in cities, increasing yet further the demand for energy, water, food, housing and other services. However, cities are struggling with climate change, changes in population and demographics, congestion, healthcare, and pressure on key resources. In the future innovative technologies/approaches will create considerable market opportunities to transform existing conurbations into the efficient, attractive and resilient cities of the future.

Nevertheless, simply applying innovative technologies alone will not guarantee the combination of sustainability and acceptable living standards for future cities… good governance and management will also play a pivotal role. This can only be provided by utilizing technological advancements optimally whilst also developing short and long term management, organization and development strategies to realize the desired objectives.

Abbreviations

BedZED: Beddington zero energy development; EPBD: energy performance of buildings directive; ETT: evacuated tube transport; EU: European Union; GWP: global warming potential; IPCC: intergovernmental panel on climate change; PV: Photovoltaic; UA: urban area; UHI: urban heat island; UHIE: urban heat island effect; UK: United Kingdom; UN: united nations; ZCB: zero carbon building; ZEB: zero energy building.

Competing interests

The authors declare that they have no competing interests.

Authors' contributions

DA and RP drafted the manuscript. SR has supervised the presented research, done the final revision of the manuscript and given final approval of the version to be published. All authors read and approved the final manuscript.

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