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SUSTAINABLE URBAN DEVELOPMENT: MODERN CONCEPTS, GLOBAL TRENDS, AND RESEARCH DIRECTIONS: A REVIEW

Mohamed Salem Mohamed Othman
University Sains Malaysia (USM), Penang, Malaysia
e-mail: salemm@usm.my

Abstract. This paper examines current global urbanization trends based on United Nations Organization data, including the growth of megacities, accelerated development of small and medium-sized cities, uneven dynamics of urban populations, and the expansion of built-up areas. Special attention is given to the "smart city" concept and integrated sustainable development strategies aimed at enhancing energy efficiency, ecological sustainability, and urban environmental quality. Promising solutions are analyzed, including green roofs, photovoltaic systems integrated into urban infrastructure, the use of innovative materials within a circular economy framework, and the role of urban greenery in providing ecosystem services. Biostatic methods for protecting architectural heritage using specialized decorative lighting are also discussed. It is shown that a comprehensive combination of technological, ecological, and managerial solutions can mitigate the negative effects of urbanization and ensure more sustainable and inclusive urban development in the face of climate and energy challenges.

Keywords: urbanization, sustainable development, smart city, digitalization, urban policy, resource efficiency.

Introduction

Urbanization is one of the most significant global trends of recent decades. Today, more than half of the world's population lives in cities, and according to United Nations projections, this share is expected to rise to two-thirds of the global population by 2050. The growth of urban populations creates both socio-economic opportunities and significant challenges that require comprehensive and systematic responses. Although urban areas occupy only about 2% of the Earth's surface, they consume 60–80% of global energy resources, which increases environmental pressure and makes cities more vulnerable to the impacts of climate change.

The main challenges of urbanization include a shortage of affordable housing, overburdened transport and utility infrastructure, deteriorating air quality, water scarcity, and increasing frequency of extreme weather events. The expansion of urbanization also exacerbates social and economic inequalities, as access to urban opportunities is distributed unevenly. In this context, implementing strategies for sustainable and inclusive urban development aimed at improving urban living conditions, energy efficiency, ecological sustainability, and public engagement in governance processes becomes highly relevant.

One of the most promising directions in modern urban development is the concept of the "smart city," which involves the use of digital technologies, data analytics, and innovative management practices to optimize urban processes, improve service quality, and ensure sustainable development. Intelligent systems for managing transportation, energy, water supply, and urban planning help reduce environmental impacts, enhance resource efficiency, and improve the quality of life for city residents. However, despite the variety of approaches in sustainable and smart development, there is no unified theoretical framework, and many concepts are often used incorrectly or interchangeably, creating methodological contradictions and complicating their practical application.

For decades, the Population Division of the UN Department of Economic and Social Affairs has been releasing updated estimates and projections of urban and rural populations for all countries, as well as their largest urban agglomerations. The UN website presents key results from the revised

edition of World Urbanization Prospects 2025, prepared based on total population data for each country included in the updated World Urbanization Prospects 2024 (United Nations, 2024). Publications in the World Urbanization Prospects series are actively used by the UN system, numerous international organizations, research institutions, scholars, and the media [1].

Below are 10 key findings on global urbanization (2025) [2] from the UN report (World Urbanization Prospects 2025: Highlights) regarding population trends:

1. The world is becoming urban.
- ✓ 45% of the population lives in cities, 36% in towns, 19% in rural areas.
- ✓ By 2050, population growth will occur mainly in cities and towns; rural population is expected to peak in the 2040s.

2. Growth of megacities.
- ✓ In 2025, there are 33 megacities (10 million+), 19 of which are in Asia.
- ✓ Jakarta is the largest city (42 million), Dhaka is growing rapidly, Tokyo is shrinking.

3. Small and medium-sized cities grow faster.
- ✓ 96% of cities have fewer than 1 million residents.
- ✓ Particularly rapid growth occurs in Africa and Asia.

4. Urban population growth is concentrated in seven countries.
- ✓ India, Nigeria, Pakistan, DR Congo, Egypt, Bangladesh, and Ethiopia will add over 500 million urban residents by 2050.

5. Uneven urban growth.
- ✓ More than 3,000 cities are losing population (mostly <250,000), especially in China and India.

6. Towns are important for sustainable development.
- ✓ Over one-third of the population lives in towns.
- ✓ Towns connect cities and rural areas and support local economies.

7. Rural populations face challenges.
- ✓ Rural population is expected to peak in the 2040s.
- ✓ Rural areas face increasing pressure from population aging and migration to cities.

8. Built-up areas grow faster than population.
- ✓ Per capita built-up area has increased from 43 to 63 m².
- ✓ 60% of new urbanized land was formerly agricultural land.

9. The world is more urbanized than national statistics show.
- ✓ According to national statistics, 58% of the population is urban, but by the “degree of urbanization” methodology, it is 81%.

10. An integrated approach to development is needed.
- ✓ Cities, towns, and rural areas are interconnected.
- ✓ Transportation, digital infrastructure, housing, land-use planning, and services are essential.

Urban development without considering green spaces increases cities’ vulnerability to climate risks. The European Union promotes the integration of buildings with nature-based solutions (NBS), including green roofs, as a strategy to enhance urban resilience. Despite their popularity, data on the environmental impacts of green roofs over their life cycle remain limited. Studies show that extensive roofs are generally more environmentally friendly than intensive ones due to lower material and irrigation requirements, while conventional flat roofs demonstrate better performance in several impact categories because they lack additional structural layers.

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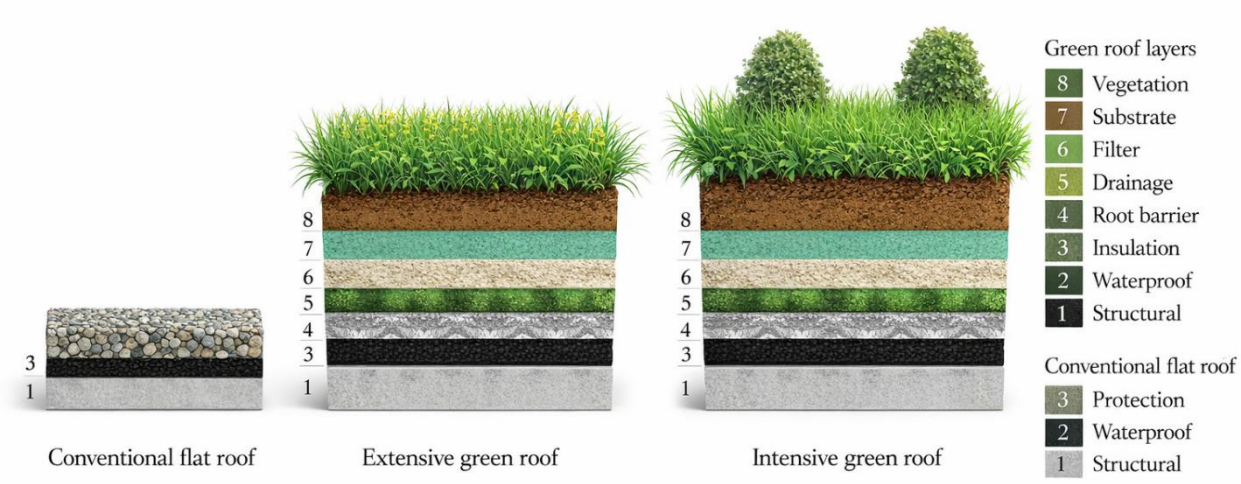


Figure 1. Schematic representation of the layers of green and conventional flat roofs [3].

A key factor influencing environmental impact is the operation and disposal stage of materials. Optimizing waste management and considering local climatic conditions can enhance the efficiency of green roofs and their contribution to sustainable urban development [3]. Climate and energy crises have increased interest in renewable energy sources, which require large areas and significant investments. One promising solution is the integration of photovoltaic systems (PV) into road surfaces..

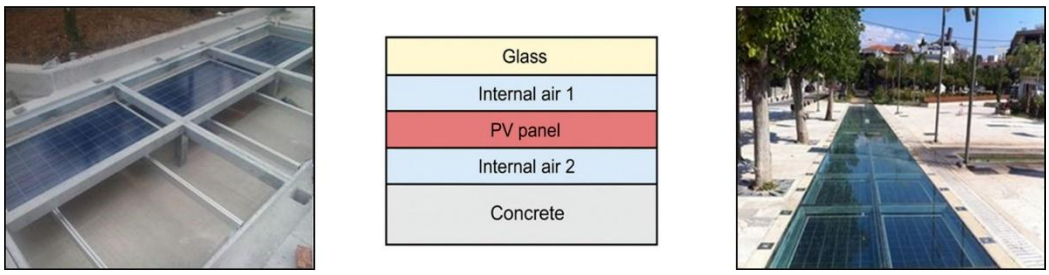


Figure 2. Solar power system: under construction (right), schematic cross-section (center), in operation (left) [4].

Studies of the pilot project in Athens showed that photovoltaic systems are capable of reducing surface temperatures compared to traditional asphalt, generating sufficient electricity for street lighting, and exerting a moderate influence on the urban microclimate. These results highlight the potential of photovoltaic systems as a sustainable urban infrastructure measure, combining energy generation with microclimate improvement. Photovoltaic systems installed on urban sidewalks serve as renewable energy sources for power generation and microclimate control [4].

Sustainable urban development requires solutions for waste reduction, emission mitigation, and efficient resource use. Transitioning to a circular economy involves the use of innovative materials such as eco-friendly pavement tiles and “green coal,” which contribute to sustainable urban infrastructure, waste reduction, and the promotion of clean energy. Existing studies mainly focus on the technical properties of these materials, whereas their environmental, economic, and social impacts are less studied. Research shows that eco-friendly tiles demonstrate high strength and durability, while “green coal” reduces CO_2 emissions and deforestation [5].

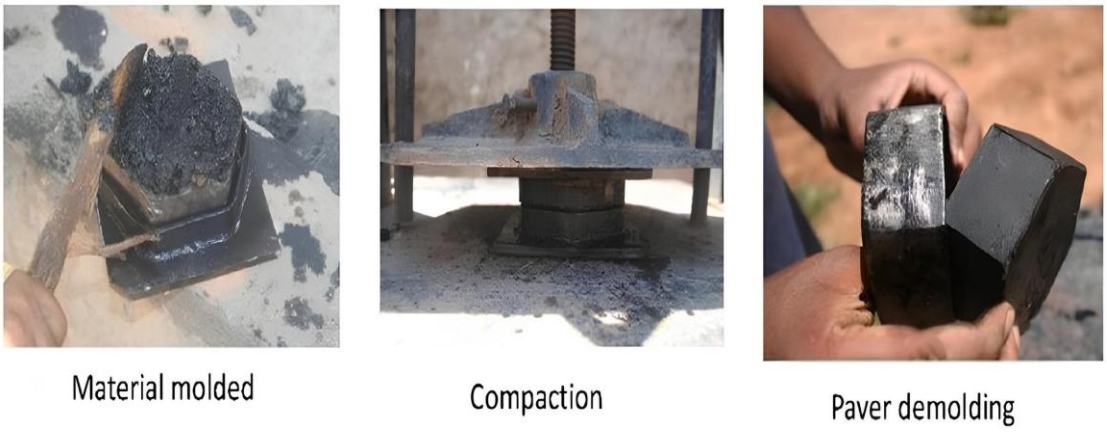


Figure 3. Process of producing paving blocks from plastic waste [5].

These solutions support local economic development and the integration of circular economy principles into urban planning, contributing to the achievement of sustainable development goals.

Promoting sustainable urban development through local production of eco-friendly paving stones and green coal [6].

The intensification of climate risks, such as droughts and storms, underscores the importance of green spaces for enhancing urban resilience. Urban vegetation provides key ecosystem services—including mitigation of the urban heat island effect, air quality improvement, carbon sequestration, and stormwater management—yet selecting optimal plant species remains a complex challenge. Recent studies propose standardized multi-criteria matrices for evaluating plants based on ecological, functional, and aesthetic criteria, taking local conditions into account.

This approach allows for the alignment of ecological and social needs, providing a practical tool for urban greening planning, biodiversity support, and enhancement of cities' climate resilience [7].

Insufficient green coverage significantly exacerbates environmental problems in urban areas. The combination of growing urban populations and the degradation of natural ecosystems necessitates innovative approaches to increase urban resilience. Studies [8] show that urban vegetation provides a broad range of ecosystem services, including reduction of the urban heat island effect, improvement of air quality through pollutant absorption, carbon accumulation in surface soil layers, and regulation of stormwater runoff. Despite the importance of these functions, the selection of optimal plant species within integrated urban greening strategies remains a complex and multifaceted task.

Research [9] indicates that mixtures of fly ash, ash residues, and soil (FABA) can serve as a sustainable material for landfill sublayers in urban environments. Evaluation of geotechnical properties and cadmium adsorption capacity showed that mixtures with moderate FABA content possess high mechanical stability, meet regulatory permeability requirements, and effectively remove heavy metals from leachate. These findings highlight the potential of FABA mixtures for environmentally safe waste management, supporting circular economy principles and sustainable urban development.

Nighttime decorative lighting can serve as a biostatic tool for controlling phototrophic colonization of architectural monuments; however, the influence of daytime illumination levels on the effectiveness of this approach remains insufficiently studied. Recent research analyzed for the first time how the amount of daylight affects biofilm response to nighttime decorative lighting. Two daylight levels—low (LDI, ~2050 lx) and high (HDI, ~10200 lx)—determined from field measurements, and three LED night lighting regimes—cool white, warm white, and a combination of amber and green light with biostatic effect—as well as a dark control, were applied [9].

Subaerial biofilms, consisting mainly of green algae (*Chlorella vulgaris*, *Klebsormidium flaccidum*) and cyanobacteria (*Synechocystis* sp.), were isolated from the surfaces of granite

monuments. The effects of daytime and nighttime light interaction were assessed through changes in biomass and diversity, biochemical composition, biofilm matrix morphology (via confocal microscopy), and photosynthetic activity (PAM fluorimetry).

Results showed that cool white light enhanced biomass growth, while amber + green light effectively suppressed it under any daylight level. Moreover, amber-green lighting reduced the relative abundance of *Klebsormidium flaccidum* under low daylight conditions and limited biofilm matrix formation. Under high daylight, decorative lighting had little effect on the biochemical profile, yet amber + green light reduced the phototroph viability index compared to other regimes.

Thus, the amber and green light combination proved highly effective in suppressing biofouling regardless of daylight exposure, opening prospects for more sustainable management of architectural heritage through specialized nighttime decorative lighting schemes [10].

Conclusions

Urbanization and the expansion of urban areas create both significant socio-economic opportunities and serious environmental and infrastructural challenges. Modern cities face housing shortages, overloaded transport and utility systems, deteriorating air quality, water scarcity, and increased vulnerability to climate risks. In this context, the implementation of comprehensive strategies for sustainable and inclusive development, based on the integration of digital technologies, smart governance solutions, and ecological approaches, becomes crucial.

The use of green roofs, urban vegetation, photovoltaic systems, and innovative materials contributes to reducing environmental impact, improving energy efficiency, and providing ecosystem services. Implementing circular economy principles, local production of eco-friendly construction materials, and regulation of light exposure on architectural heritage open new opportunities for sustainable urban planning.

Thus, the comprehensive combination of technological, ecological, and socio-managerial measures not only mitigates the negative effects of urbanization but also enhances the quality of urban life, supports biodiversity, and strengthens climate resilience. Thoughtful and systematic application of these solutions is essential for developing modern cities that harmoniously combine economic development, environmental sustainability, and comfortable living conditions.

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ҚАЛАЛАРДЫҢ ТҰРАҚТЫ ДАМУЫ: ЗАМАНАУИ ТҰЖЫРЫМДАМАЛАР, ЖАҺАНДЫҚ ҮРДІСТЕР ЖӘНЕ ҒЫЛЫМИ БАҒЫТТАР: ШОЛУ

Мохамед Салем Мохамед Отман
Сайнс Малайзия Университет (USM), Пинанг, Малайзия
e-mail: salemm@usm.my

Аңдатпа. Жұмыста БҰҰ мәліметтері негізінде әлемдік урбанизацияның қазіргі тенденциялары қарастырылады, соның ішінде мегаполистердің өсуі, шағын және орта қалалардың қарқынды дамуы, қалалық халықтың біркелкі емес динамикасы және құрылысы кеңейіп жатқан аумақтар. Арнайы назар «ақылды қала» тұжырымдамасына және энергия тиімділігін, экологиялық тұрақтылықты және қалалық орта сапасын арттыруға бағытталған интеграцияланған тұрақты даму стратегияларына аударылады. Зиянсыз шешімдер ретінде жасыл шатырлар, қалалық инфрақұрылымға біріктірілген фотоэлектрлік жүйелер, жабық цикл экономикасы аясында инновациялық материалдарды қолдану, сондай-ақ экожүйелік қызметтерді қамтамасыз етудегі қалалық жасыл желектердің рөлі талданды. Мамандырылған декоративті жарықтандыру арқылы сәулет мұрасын қорғаудың биостатикалық әдістері жеке қарастырылды. Көрсетілгендей, технологиялық, экологиялық және басқарушылық шешімдердің кешенді үйлесімі урбанизацияның теріс салдарын азайтып, климаттық және энергетикалық мәселелер жағдайында қалалардың тұрақты әрі инклюзивті дамуын қамтамасыз ете алады.

Түйін сөздер: урбанизация, тұрақты даму, ақылды қала, цифрландыру, қалалық саясат, ресурс тиімділігі.

УСТОЙЧИВОЕ РАЗВИТИЕ ГОРОДОВ: СОВРЕМЕННЫЕ КОНЦЕПЦИИ, ГЛОБАЛЬНЫЕ ТЕНДЕНЦИИ И НАУЧНЫЕ НАПРАВЛЕНИЯ: ОБЗОР

Мохамед Салем Мохамед Отман
Университета Сайнс Малайзия (USM), Пинанг, Малайзия
e-mail: salemm@usm.my

Аннотация. В работе рассматриваются современные тенденции мировой урбанизации на основе данных ООН, включая рост мегаполисов, ускоренное развитие малых и средних городов, неравномерную динамику городского населения и расширение застроенных территорий. Особое внимание уделено концепции «умного города» и интегрированным стратегиям устойчивого развития, направленным на повышение энергоэффективности, экологической устойчивости и качества городской среды. Проанализированы перспективные решения, включая зелёные крыши, фотоэлектрические системы, интегрированные в городскую инфраструктуру, использование инновационных материалов в рамках экономики замкнутого цикла, а также роль городских зелёных насаждений в обеспечении экосистемных услуг. Отдельно рассмотрены биостатические методы защиты архитектурного наследия с использованием специализированного декоративного освещения. Показано, что комплексное сочетание технологических, экологических и управленческих решений способно снизить негативные последствия урбанизации и обеспечить более устойчивое и инклюзивное развитие городов в условиях климатических и энергетических вызовов.

Ключевые слова: урбанизация, устойчивое развитие, умный город, цифровизация, городская политика, ресурсоэффективность.