

TECHNOLOGIES FOR A GREEN CITY: DIGITAL AND ECO-FRIENDLY BUS STOPS

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Introduction

Modern cities face a range of challenges in organizing public transport: road congestion, long bus waiting intervals, inefficient resource use, and high levels of greenhouse gas emissions. One effective solution is the implementation of **smart and eco-friendly bus stops**, which integrate digital technologies, energy-efficient systems, and green elements, enhancing passenger comfort and safety.

It is particularly important that such stops are located on **non-agricultural lands**, allowing the use of urban and infrastructure areas without impacting agricultural activities. This ensures compliance with urban planning regulations and maintains a balance between transport development and the preservation of fertile land.

The aim of this article is to explore modern technologies and practices in creating digital and eco-friendly bus stops, analyze international experiences of their implementation, and evaluate the impact of such solutions on urban sustainability. Key components of smart stops highlighted in the article include real-time information systems, energy-efficient lighting, renewable energy use, integration of green spaces, and passenger-friendly infrastructure.

2. Technological and Ecological Solutions for Smart Bus Stops

Modern smart and eco-friendly bus stops combine **digital technologies, energy-efficient systems, and green elements**, making them convenient for passengers and environmentally sustainable for cities.

Digital Information Systems

- **Real-time display boards: show accurate bus arrival times and routes, reducing waiting time.**
- **Integration with mobile applications:** passengers can receive notifications, plan routes, and pay for fares online.
- **Accessibility information panels:** visual and audio alerts for people with disabilities.

Energy-Efficient Solutions

- **Solar panels** on the roof for autonomous power supply to lighting and digital devices.
- **LED lighting** with motion sensors, activated only when needed to reduce energy consumption.
- **Rainwater collection systems** for irrigating green spaces at the bus stop.

Ecological and Green Elements

- **Vertical and container gardens**, as well as green roofs, which absorb CO₂, improve microclimate, and create a comfortable environment.

- **Low-carbon materials**: use of recycled or eco-friendly building materials for platforms, shelters, and benches.

- **Integration with the urban ecosystem**: planting native plants, creating mini-rest areas, and shaded zones for passengers.

Passenger Comfort and Safety

- **Protection from rain and sun**, comfortable seating, and accessible areas for people with reduced mobility.

- **CCTV and emergency alert systems** to enhance security.

- **Interactive panels and QR codes** for information on routes, city services, and tourist attractions.

The combination of these solutions makes smart bus stops **eco-friendly, energy-efficient, and comfortable**, increases the attractiveness of public transport, and encourages city residents to use it instead of personal vehicles.

3. International Experience in Implementing Smart and Eco-Friendly Bus Stops

In many countries, smart and eco-friendly bus stops are becoming integral parts of urban infrastructure aimed at **transport digitalization, improved passenger service, and sustainable development**.

China. In several Chinese cities, **electronic displays showing real-time bus arrival information** have been installed on major corridors, enhancing passenger convenience and reducing uncertainty in waiting times. These initiatives began, for example, in Ji'an, Jiangxi Province in 2016, although their continuity may rely on commercial funding models. [1]

South Korea. Seoul tested high-tech Smart Shelter bus stops equipped with air conditioning, digital screens, cameras, and solar panels. These stops also offer free Wi-Fi, device charging areas, and climate control systems to adapt to heat, rain, and public health conditions.[2]

Japan. Japan implemented a project featuring solar-powered e-paper displays at bus stops to show schedules and arrival information in real time. These displays are powered independently of the grid, reducing operational costs and supporting sustainability.[3]

Germany. In Germany and across Europe, solar-powered bus stops with real-time digital signage have become more common, reflecting a broader push for green transportation infrastructure that combines renewable energy with digital services.[4]

Sweden. Swedish cities integrate smart bus stops into sustainable mobility networks that include information displays and energy-efficient technologies as part of

broader smart city initiatives. Cities like Stockholm frequently feature in international smart city indexes for transportation innovation. [5]

France. In France, companies such as RATP Smart Systems develop digital passenger information technologies, including schedules and route displays integrated with mobile and automated transit systems, which are increasingly deployed at bus stops to enhance information delivery. [6]

European Context. Across Europe, solar-powered, digitally enabled bus stops form part of urban sustainability strategies by combining real-time information, renewable energy, charging stations, and LED lighting to reduce carbon footprints and improve passenger experience. [7]

Comparative Analysis of Smart and Eco-Friendly Bus Stops in Different Countries

Country	Technologies & Features	Energy Source	Green Elements	Interactive Features	Implementation Level / Examples
China	Digital displays with real-time bus arrivals, mobile app integration	Electricity, partially solar panels	Vertical gardens, green roofs	Route planning, online payment, notifications	Beijing, Shanghai, Ji'an
South Korea	Interactive panels, cameras, climate control systems	Solar panels	Vertical greenery	Wi-Fi, device charging, safety systems	Seoul, pilot Smart Shelter stops
Japan	E-paper displays, IoT transport occupancy monitoring	Solar panels	Small trees, shrubs, green zones	Route and schedule information	Tokyo, Osaka
Germany	Real-time digital displays, information panels	Solar panels	Flower beds, container gardens	Mobile apps for route planning	Berlin, Munich

Sweden	Automated transport monitoring, digital displays	Solar panels, LED lighting	Green plantings at stops	Real-time route and congestion info	Stockholm, sustainable transport systems
France	Digital displays, integration with multimodal transport	Electricity, solar panels	Green roofs, planted areas	QR codes, mobile apps	Paris, RATP Smart Systems

4. Impact of Smart and Eco-Friendly Bus Stops on Passenger Behavior and Sustainable Mobility

The implementation of smart and eco-friendly bus stops has a **significant impact on passenger behavior, travel habits, and the environmental sustainability of cities**. Modern technologies and green elements at stops create a comfortable, safe, and eco-friendly waiting environment, encouraging the use of public transportation.

Reduced waiting times and improved convenience

Digital displays and mobile applications providing real-time bus arrival and route information allow passengers to **plan their trips more accurately**, reducing waiting time. This is especially important in large cities where transportation is congested and intervals between buses can be long. Smart notifications via smartphones or interactive panels increase passenger awareness and reduce stress caused by uncertainty.

Formation of ecological awareness

Green elements at stops — vertical gardens, container plants, and green roofs — create a **visual emphasis on the ecological nature of urban infrastructure**. Seeing the city's efforts to maintain sustainability encourages passengers to choose public transport over personal vehicles, reducing road congestion and greenhouse gas emissions.

Integration with multimodal systems

Smart stops are often part of a **multimodal mobility system**, combining buses, metro, bike-sharing stations, and e-scooters. This provides passengers with **flexible routes and convenient transfers**, reduces travel times, and promotes decreased reliance on private cars.

Promotion of digital habits among citizens

Interactive panels, QR codes, and mobile apps allow passengers to **pay fares, plan routes, and receive real-time information on transport occupancy**. Regular use of such services fosters digital habits, increases engagement, and facilitates the integration of the city into a smart transport ecosystem.

Socio-psychological influence

Comfortable, safe, and visually appealing stops increase passenger satisfaction and create a sense of care from the city administration. The presence of green spaces and comfortable seating encourages a positive attitude toward public transportation, enhances social engagement, and fosters responsibility for maintaining the urban environment.

Example: In Stockholm and Seoul, the implementation of digital displays and green bus stops increased public transport usage by 5–12% and reduced the average carbon footprint per route.

5. Economic and Environmental Benefits of Smart and Eco-Friendly Bus Stops

The implementation of smart and eco-friendly bus stops has a **comprehensive impact on the economy, ecology, and social environment of cities**, making transportation infrastructure more sustainable and efficient. This approach combines digital technologies, green elements, and energy-efficient solutions, providing long-term benefits.

Reduction of operational costs and energy consumption

The use of **solar panels to power digital displays, LED lighting, and information panels** significantly reduces electricity consumption and operational costs for city services.

Energy-independent stops powered entirely by solar energy eliminate the need for connection to the city grid, lowering electricity costs and reducing infrastructure load.

Smart lighting management systems, motion sensors, and automatic brightness adjustment further **optimize energy use**.

Increased revenue and public transport usage

Comfortable and informative stops enhance **passenger satisfaction**, reduce waiting stress, and make public transport more attractive.

Higher passenger numbers lead to increased **ticket and subscription revenue**, especially with integrated payment systems via mobile apps or electronic cards.

Growth in passenger flow reduces reliance on private vehicles, lowering the need for expanding roads and parking areas, which is economically beneficial for cities.

Environmental and climate benefits

Green elements — vertical gardens, container plants, green roofs, and mini-park zones — **absorb CO₂, reduce microclimate temperatures, and improve air quality**.

Reduced private vehicle usage due to attractive public transport decreases **greenhouse gas emissions, noise pollution, and road congestion.**

Combined with solar panels and energy-efficient lighting, such stops create **low-carbon infrastructure**, supporting cities' environmental goals and sustainable development programs.

Long-term social and image benefits

Comfortable, safe, and aesthetically appealing stops increase **social satisfaction and trust in city administration.**

Green areas and comfortable seating create a sense of care for residents, fostering positive attitudes toward urban spaces and public transportation.

Development of "green" infrastructure enhances the city's appeal to tourists and investors, strengthening its image as an **innovative and environmentally responsible city.**

These stops become part of a **smart city strategy**, integrating with digital transport monitoring, passenger flow management, and environmental control systems.

Implementation examples

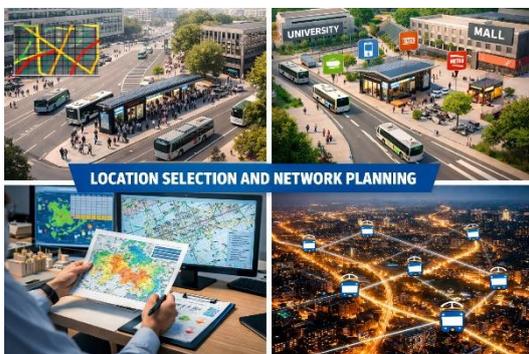
Seoul, South Korea: solar-powered stops with digital displays and green elements reduced electricity consumption by 30–40% and increased bus usage on the routes with these stops.

Tokyo, Japan: integration of solar-powered e-paper displays reduced energy costs and improved accuracy of transport movement information.

Stockholm, Sweden: combined digital and green stops promoted increased passenger flow and fostered sustainable public transport habits.

Recommendations for Implementing Smart and Eco-Friendly Bus Stops

1. Location selection and network planning



The effective implementation of smart and eco-friendly bus stops requires a systematic approach to location selection. It is optimal to place stops in areas with high passenger density, near route intersections and transport hubs, as well as close to educational and commercial facilities. This approach ensures maximum return on investment and enhances the overall functionality of the transport network.

Network planning should consider integration with existing infrastructure, potential expansion, and future route changes. Passenger flow analysis, peak load assessments, and demographic and social characteristics of neighborhoods must be taken into account to design a network that provides even passenger distribution and minimizes waiting times.

Technological equipment and digitalization



Smart stops should be equipped with digital information systems, including displays showing real-time transport arrival data, integrated with mobile applications for route planning. These technologies provide passengers with up-to-date information, increase trip planning accuracy, and reduce stress associated with waiting.

To enhance energy efficiency, the use of solar panels, LED lighting, and intelligent energy management systems is recommended.

Additionally, Wi-Fi points, USB charging ports, and surveillance systems can be installed to ensure passenger safety and comfort. Integrating these technologies creates infrastructure that meets modern smart city standards.

Green elements and sustainable construction



Green zones at stops — vertical gardens, container plants, and mini-park areas — contribute to the creation of a favorable microclimate and improved urban environment. The presence of vegetation reduces heat radiation, improves air quality, and creates a visually attractive and comfortable waiting environment.

It is recommended to use environmentally safe and recycled materials for construction, such as metal, glass, and composites. This approach ensures durability, minimizes the environmental

footprint, and demonstrates the city's commitment to sustainable development principles.

Integration with a multimodal transport system

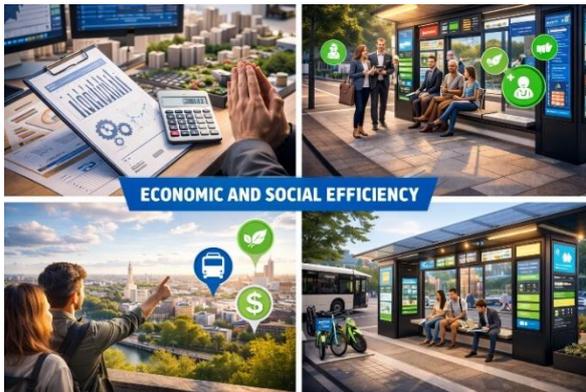


To enhance passenger convenience, smart stops should be part of a multimodal transport system, including buses, metro, bike-sharing, and e-scooters. Such integration allows passengers to plan routes with minimal transfer times and effectively use different modes of transport.

The development of mobile applications and web platforms enables fare payment, real-time information on transport occupancy, and timely trip planning. Interactive services increase passenger engagement and encourage the

sustainable use of public transport.

Economic and social efficiency



Smart and eco-friendly stops reduce operational costs through the use of renewable energy sources and energy-efficient technologies. Reduced electricity and maintenance costs make the project economically viable in the long term.

Social efficiency is expressed in increased passenger satisfaction, improved urban environment quality, and the development of public transport usage habits. Comfortable, safe, and visually attractive stops foster public trust in city administration and enhance social activity.

Conclusion

The implementation of smart and eco-friendly bus stops contributes to the efficiency of urban transport systems and improves the quality of life for residents. The use of digital technologies, such as information displays, mobile applications, and integration with multimodal routes, allows passengers to plan their trips more conveniently and reduces waiting times, increasing overall satisfaction with transport services.

Environmental elements, including green roofs, vertical gardens, and the use of renewable energy sources, make stops sustainable and minimize their environmental impact. These solutions help reduce the carbon footprint and energy consumption, shaping the image of a “green city” and promoting public awareness of sustainable development issues.

The practical implementation of such projects in Uzbekistan would create safe, convenient, and environmentally friendly transport infrastructure. The adoption of advanced technologies and integration of stops with other modes of transport ensures social and economic efficiency, supporting the development of sustainable urban mobility and enhancing the investment attractiveness of urban areas.

References

1. <https://www.fareast.mobi/en/feature/gibusjul22/Bus-Stop-Real-Time-Info-Displays-China-Experience>
2. https://www.mckinsey.com/ru/~/_/media/mckinsey/locations/europe%20world/transport-systems-of-25-cities-of-the-world-ru.pdf
3. <https://www.papercast.com/case-study/first-smart-bus-stop-in-japan-using-electronic-paper>
4. <https://www.euro-inox.org/solar-powered-bus-stops-transform-european-public-transit>
5. <https://ru.wikipedia.org/wiki>
6. https://en.wikipedia.org/wiki/RATP_Smart_Systems
7. <https://www.euro-inox.org/solar-powered-bus-stops-transform-european-public-transit>