MACeIP: A Multimodal Ambient Context-enriched Intelligence Platform in Smart Cities

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Source: https://www.isarsoft.com/article/smart-city-strategy-the-foundation-of-every-smart-city

Motivation

Global Trends of Smart Cities

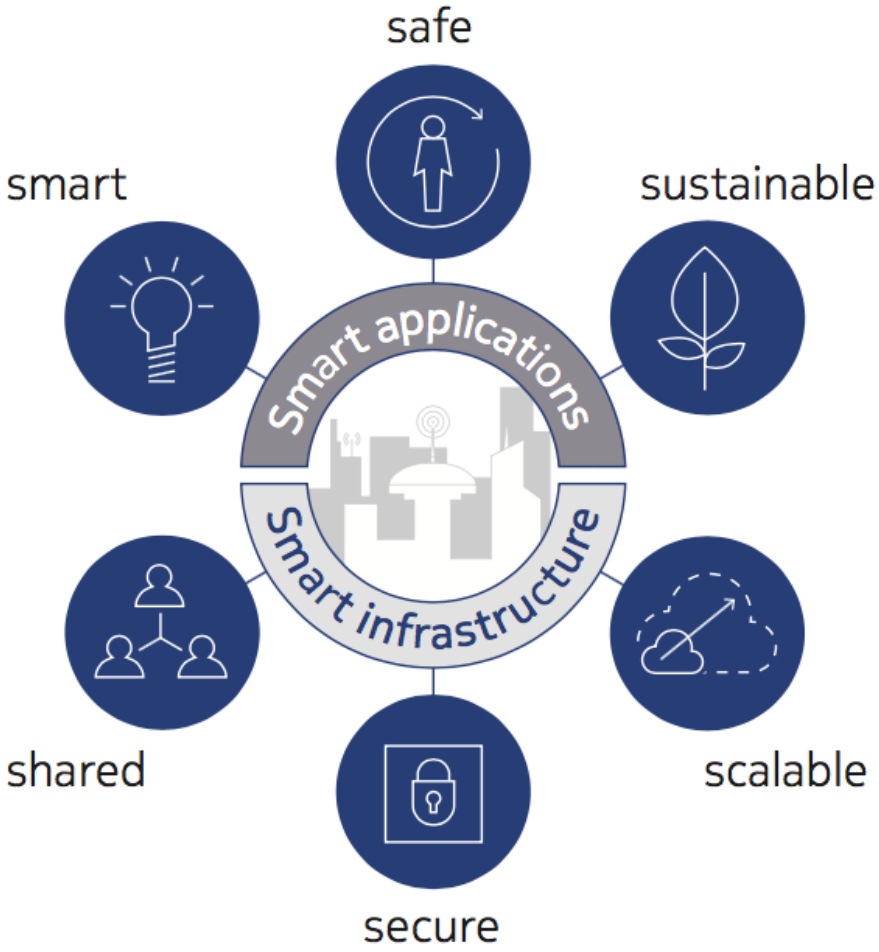
- As of 2024, more than **500 smart cities** are being developed worldwide, with significant projects in Asia, Europe, and North America.
- The global smart city market is expected to reach **$1.03 trillion** by 2025, driven by IoT, AI, and cloud technology advancements.
- Over **55%** of the global population lives in urban areas, and smart city projects aim to improve the quality of life for **4.2 billion** city dwellers by 2030.

Smart City Observatory 2024
Source: https://www.imd.org/smart-city-observatory/home/

Current Gaps in Smart Cities Solutions

Many smart city platforms:

- **Fragmented Data Systems:** They lack a data fusion, multimodal approach that integrates real-time data from diverse sources.
- **Lack of Transparency and Citizen Trust:** They collect data, but the decision-making processes and algorithms that use it are often opaque to citizens.
- **Insufficient Focus on Safety and Security:** They do not fully address urban safety challenges (crime prevention, emergency response, and public safety monitoring.)
- **Environmental and Sustainability Gaps:** They lack the ability to monitor and manage key environmental factors such as air quality, waste management, and energy consumption.

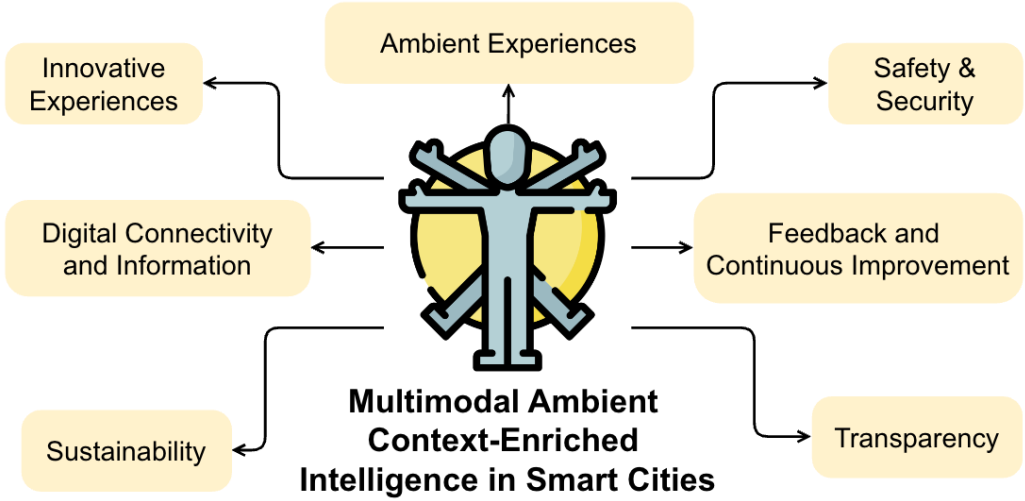


Source: https://cities-today.com/industry/six-ss-for-smart-city-successes/

Why Multimodal Ambient Context-enriched Intelligence Platform (MACeIP)?

We proposed MACeIP:

- **A Citizen-Centric Smart City**: Provides citizens with real-time services for better experiences and safety with continuous feedback.
- **Responsible and Explainable AI (XAI)**: Ensures AI-driven decisions are transparent and understandable, building citizen trust.
- **Sustainability:** Integrates an IoT network to monitor environmental conditions (air quality, water levels/quality, garbage bin status).
- **Unified Multimodal Platform:** Integrates a multimodal platform combining various real-time data sources, improving efficiency and decision-making.

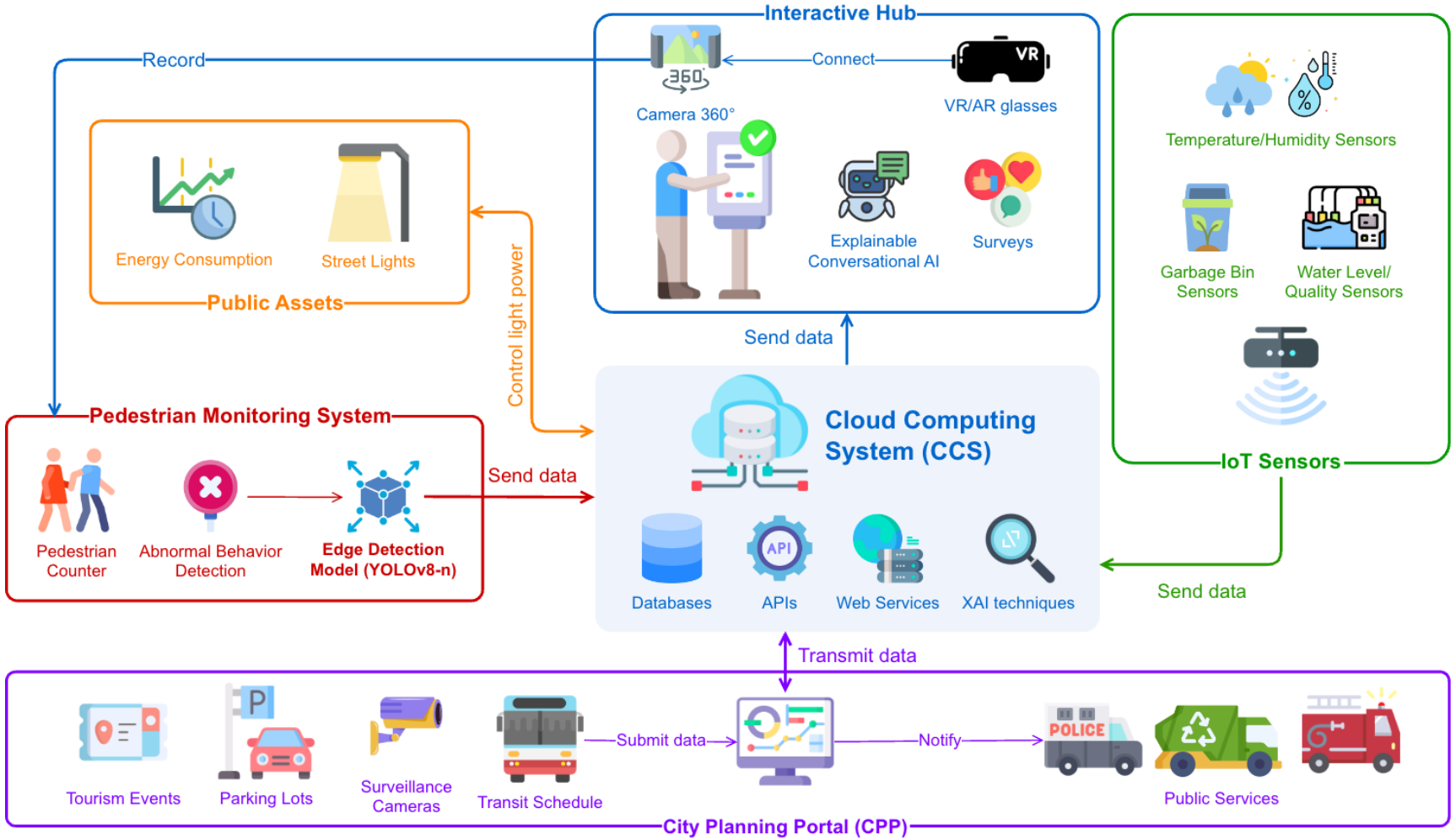


Orchestration

Orchestration Overview

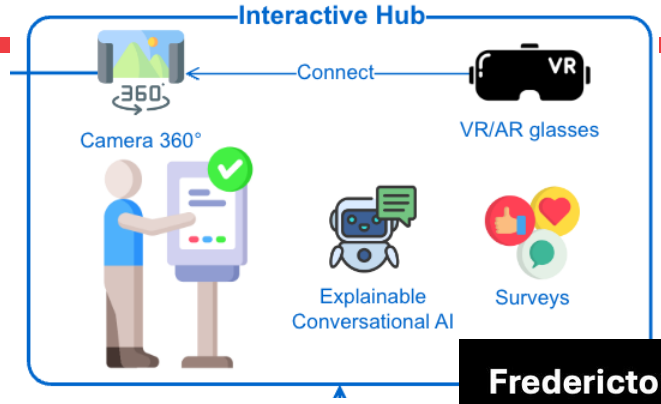
Key components:

- Interactive Hub
- IoT sensor network
- Public asset management
- Pedestrian monitoring system
- City Planning Portal (CPP)
- Cloud Computing System (CCS)



1 – Interactive Hubs

Interaction point between citizens and the city's smart infrastructure



Real-Time Information:

- Displays local weather updates, public transportation schedules, event listings, and parking availability.

AI-Powered Assistance:

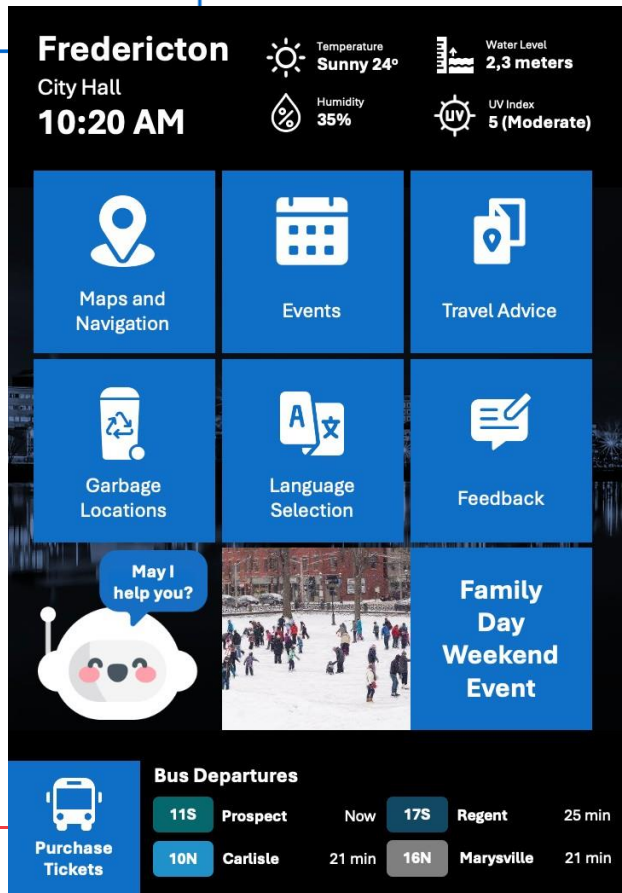
- Powered by **Explainable Conversational AI** (GPT-4o mini) integrated with **XAI** techniques (e.g., G-CAME, D-CLOSE) for transparent, understandable interactions.
- Supports multilingual communication, enhancing inclusivity for diverse populations.

VR/AR Capabilities:

- Offers immersive virtual tours of city landmarks via **360° cameras**.
- Enables users to explore public services and navigate the city virtually.

Public Service Access:

- Interactive buttons to access services like public transit, emergency contacts, and event tickets.
- Option to submit feedback, report issues, and engage with city surveys.

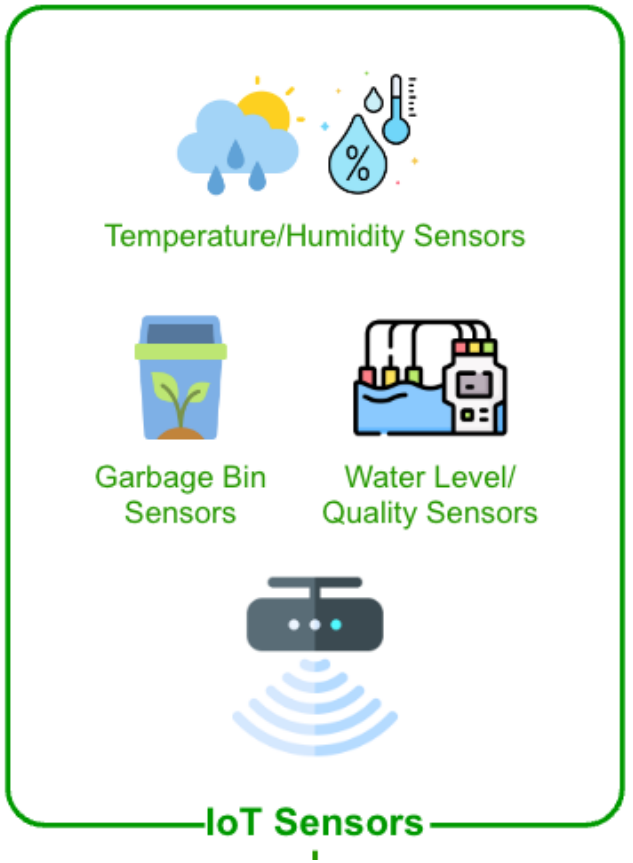


2 – IoT Sensor Network

Deployment of IoT sensors throughout the city for urban management

Key sensors:

- **Temperature and Humidity Sensors (DHT22)**: Monitors real-time weather conditions to help optimize public spaces and infrastructure.
- **Water Level Sensors (HC-SR04)**: Tracks water levels in reservoirs and flood-prone areas for disaster prevention and water management.
- **Water Quality Sensors (TDS Meter)**: Measures water quality (Total Dissolved Solids) to ensure safe drinking water and monitor contamination levels.
- **Garbage Bin Sensors (HC-SR04)**: Detects garbage bin status to optimize waste collection routes and reduce overflow incidents.
- **Air Quality Sensors (MQ-135)** Monitors harmful gases (CO2, NH3, NOx) to maintain healthy air quality levels across the city.
- **UV Index Sensors (VEML6070)**: Measures ultraviolet radiation to provide public safety alerts and adjust outdoor activity recommendations.

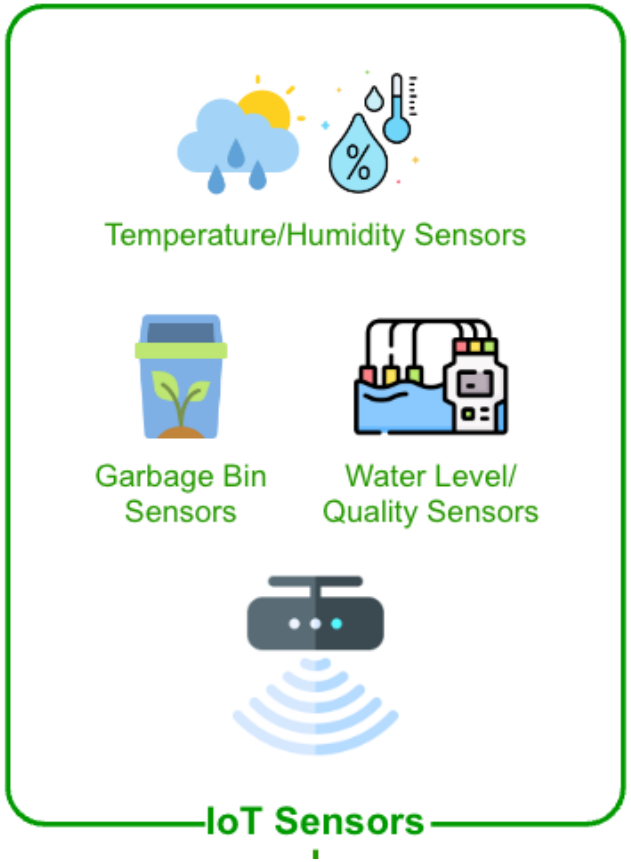


2 – IoT Sensor Network

Deployment of IoT sensors throughout the city for urban management

Data Transmission:

- **LoRaWAN Protocol**: Ensures efficient, long-range, low-power communication between IoT sensors and the cloud infrastructure.
- **Edge Computing**: Processes sensor data locally, reducing cloud load and latency and allowing for real-time decisions.

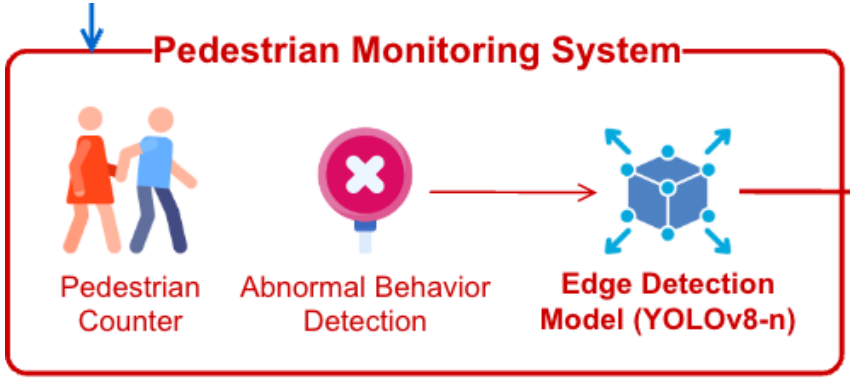


3 – Pedestrian Monitoring System

Network of cameras combined with advanced AI models to ensure public safety.

Features:

- **360° Cameras and Surveillance Systems**: Installed at key public locations (e.g., Interactive Hubs) to provide coverage of urban spaces.
- **Edge Detection Models (YOLOv8-n):** Uses lightweight models for real-time pedestrian detection and abnormal behavior monitoring at the edge.
  - **Pedestrian Counting**:
    - Tracks foot traffic in busy areas to optimize infrastructure usage, crowd management, and event planning.
  - **Abnormal Behavior Detection**:
    - Identifies suspicious or abnormal activities (e.g., fighting, falls, accidents) in public areas and notifies relevant authorities for immediate response.

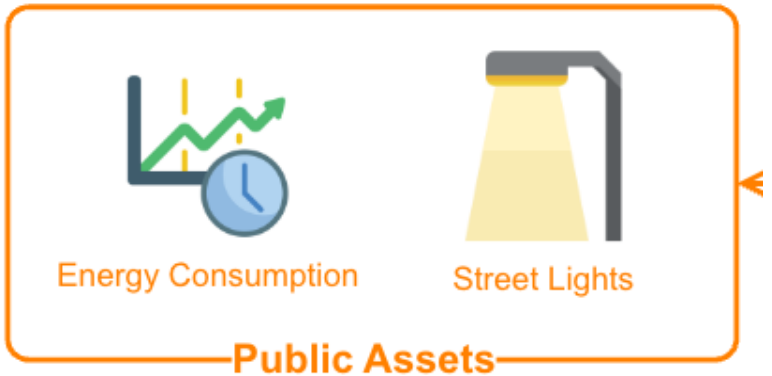


4 – Public Asset Management

Manages public assets like street lighting, parking, and other utilities

Features:

- **Smart Street Lighting**:
  - Remote-controlled streetlights with real-time energy consumption tracking.
  - Adjusts light intensity based on pedestrian flow, events, weather, and time of day using **time-series forecasting (LSTM models)**.
- **Energy Management**:
  - Historical energy usage data forecasts demand, allowing proactive resource allocation and reducing waste.
- **Parking Management**:
  - Integrates with **Interactive Hubs** and IoT sensors to provide real-time parking availability, helping citizens find parking faster and reducing congestion.



5 – City Planning Portal (CPP)

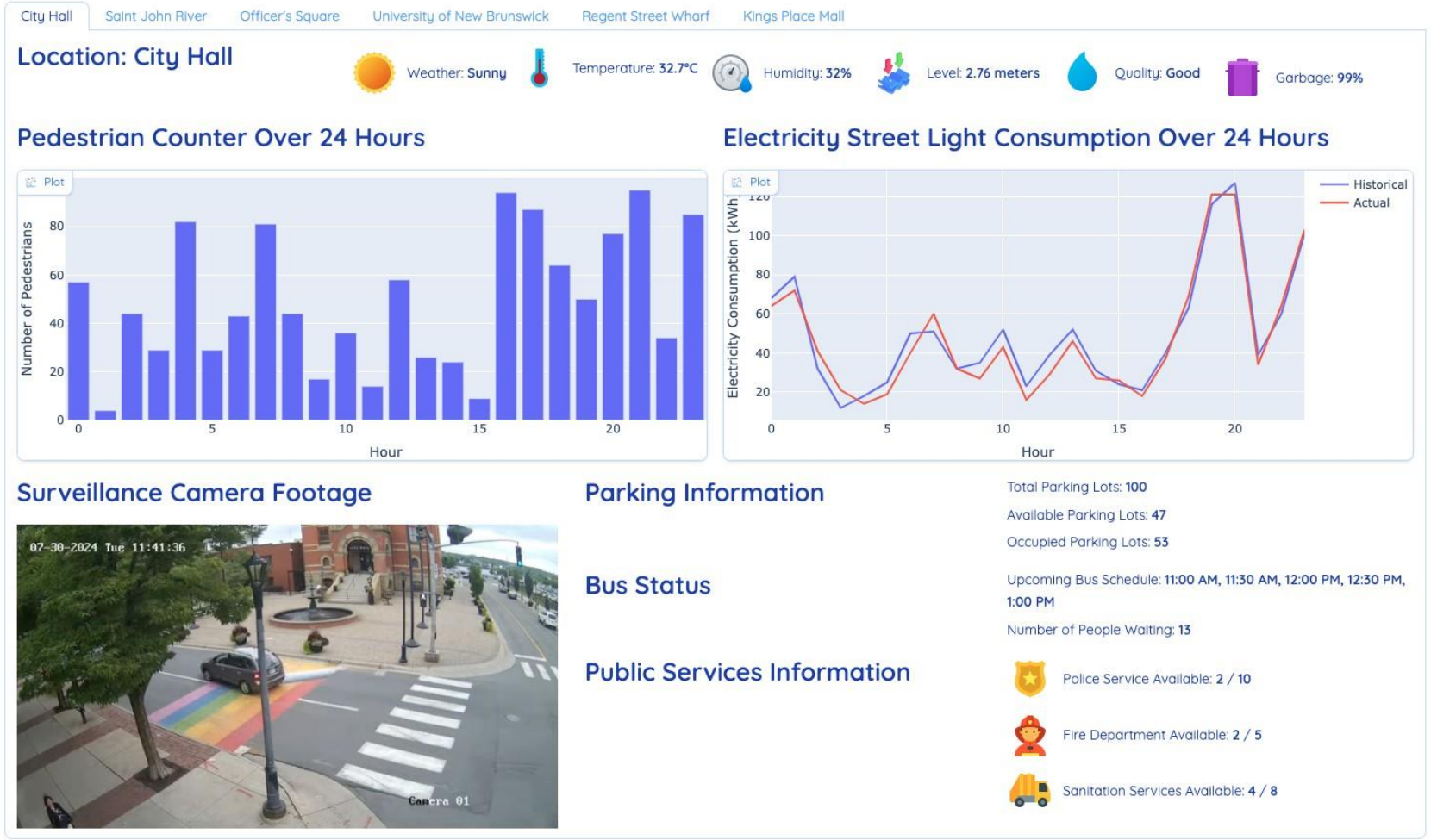
Control center for urban planners, administrators, and decision-makers

Features:

- **Real-Time Metrics**:
  - Displays data from IoT sensors, real-time pedestrian monitoring, public assets, and environmental conditions.
  - Includes customizable metrics such as energy consumption, pedestrian counts, and weather data.
- **Data Visualizations**:
  - Interactive graphs and dashboards for city administrators to analyze trends and make data-driven decisions.
  - Real-time visualizations aid in long-term planning and immediate response to city events.
- **Notification and Alert System**:
  - Generates automated alerts based on predefined rules for emergency responses, traffic conditions, and public safety.
  - Notifies relevant city departments (e.g., police, fire services) for coordinated action.

5 – City Planning Portal (CPP)

User Interface



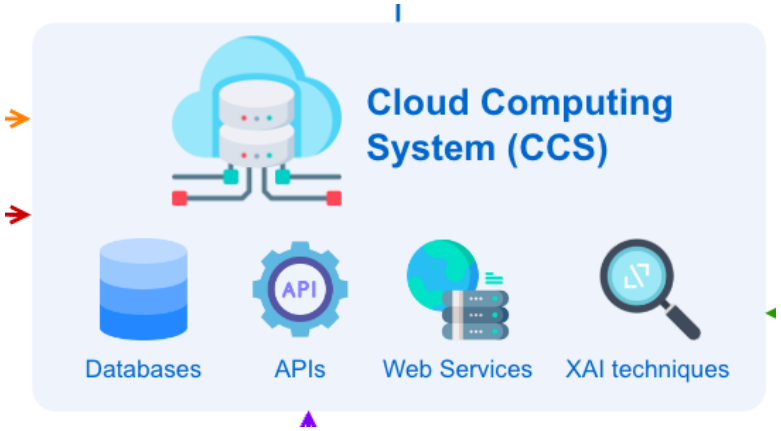
The City Planning Portal (CPP) User Interface

6 – Cloud Computing System (CCS)

Computational and Storage Infrastructure of the entire MACeIP

Components:

- **Data Management (Azure Cosmos DB)**:
  - Manages diverse data types (structured, unstructured, vector data), ensuring global distribution and scalability for large smart cities.
- **API Management (Azure API Management)**:
  - Ensures secure, scalable API integration between the platform components, allowing seamless service communication.
- **Web Services (Azure App Services)**:
  - Manages web applications and services, such as the **City Planning Portal (CPP)** and **Interactive Hub**, ensuring they are always available and responsive.
- **Multimodal AI Management (Azure AI and ML)**:
  - Supports AI model training, deployment, and management with integrated Responsible AI dashboards to ensure transparency.

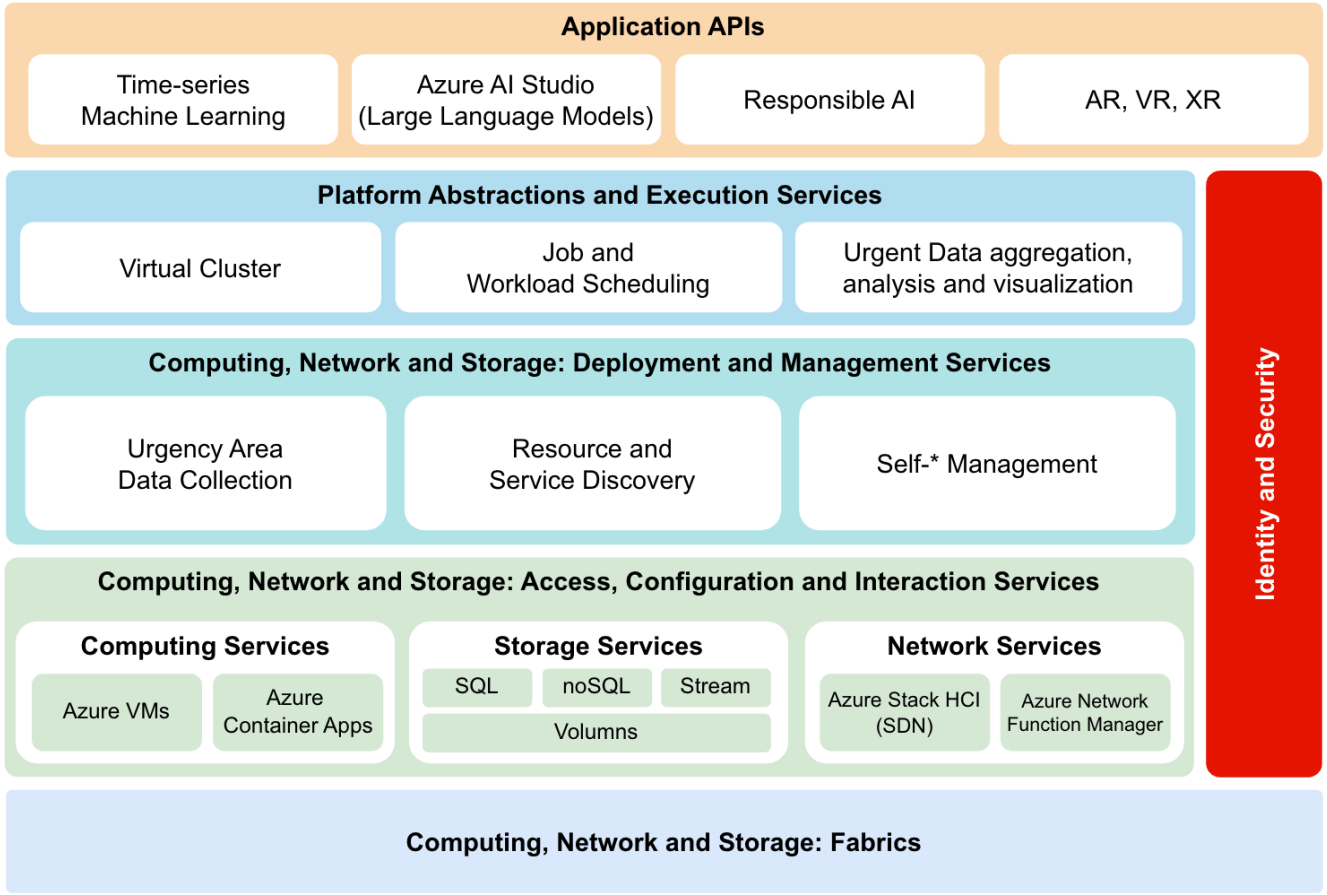


Implementation

Conceptual Architecture

We use the five-layer edge computing architecture designed to support real-time, data-driven smart city applications:

1. **5 key layers:**
   - Application APIs
   - Platform Abstractions and Execution Services
   - Deployment and Management Services
   - Access, Configuration, and Interaction Services
   - Computing, Network, and Storage – Fabrics
2. **Security and Resource Management**



Conceptual Architecture

5-layer edge computing architecture designed to support real-time, data-driven smart city applications

Key Layers:

- **Computing, Network, and Storage – Fabrics**: Physical and virtual resources (IoT sensors, edge devices, Azure cloud) form the data collection and processing backbone.
- **Access, Configuration, and Interaction Services:** Provides interfaces for configuring and accessing resources (Azure VMs, Azure Container Apps, SDN).
- **Deployment and Management Services**: Manages resource deployment, discovery, and self-* capabilities (self-healing, self-scaling), prioritizing urgency-aware tasks like public safety.
- **Platform Abstractions and Execution Services**: Offers job scheduling, data aggregation, and virtual cluster management for AI models and real-time city data processing.
- **Application APIs**: APIs for AI/ML models and immersive experiences (AR/VR) for smart city applications like CPP and Interactive Hubs.

Security and Resource Management:

- **Identity/Security**: Secures data access and transmission.
- **Urgency-Aware Resource Management**: Dynamically allocates resources to critical tasks based on real-time needs (e.g., emergency responses, traffic control).

Prototype Installation in Fredericton

MACeIP deployment in key public locations across the city

Interactive Hubs:

- **Total Hubs**: 10 locations
  - 6 hubs in parking lots
  - 4 hubs in public and tourist areas
- **Functions**: Provide real-time services such as transit schedules, event listings, and public service information to citizens and tourists.

Smart City Capabilities:

- **Pedestrian Monitoring**: Real-time pedestrian counting and abnormal behavior detection for public safety.
- **Public Assets**: Smart street lighting and parking availability connected to the platform for efficient resource management.
- **Citizen Engagement**: Hubs enable direct interaction with city services, enhancing citizen participation in city planning.

Conclusion

Multimodal Ambient Context-enriched Intelligence Platform (MACeIP)

MACeIP provides a scalable and citizen-centric platform for smart city management:

- **Comprehensive Smart City Platform**: MACeIP integrates IoT sensors, edge computing, and multimodal AI to enhance urban management and citizen engagement.
- **Citizen-Centric Design**: Interactive Hubs foster direct citizen interaction with city services, promoting engagement and feedback.
- **Scalable and Sustainable**: The platform is scalable to cities of various sizes and emphasizes sustainability through energy optimization and environmental monitoring.
- **Transparent AI**: The use of Explainable AI (XAI) builds trust and ensures data privacy and compliance with ethical standards.

Source: https://canada.constructconnect.com/joc/news/infrastructure/2019/05/western-canada-left-smart-cities-wins

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