SmartCitySim – AI-Powered Sustainable City Simulation Game (Design Document)

Title Page

Game Title: SmartCitySim – AI-Powered Sustainable City Simulation Game
Version Number: 1.0
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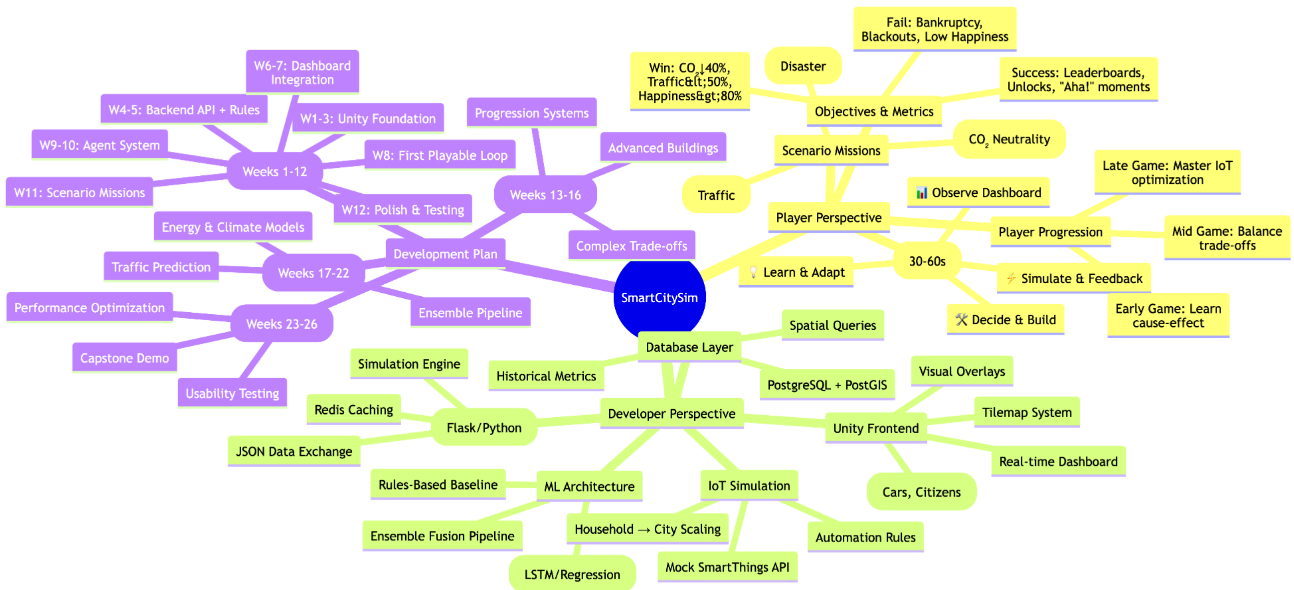


See Figure 1: SmartCitySim - Complete Architecture Mindmap

Executive Summary / Project Overview

SmartCitySim is a **serious game** that blends **Sims/SimCity-inspired city-building mechanics** with **real-time sustainability analytics**. Players act as **urban planners**, making choices that impact **traffic flow, CO_2 emissions, energy use, flood risk, and citizen happiness**.

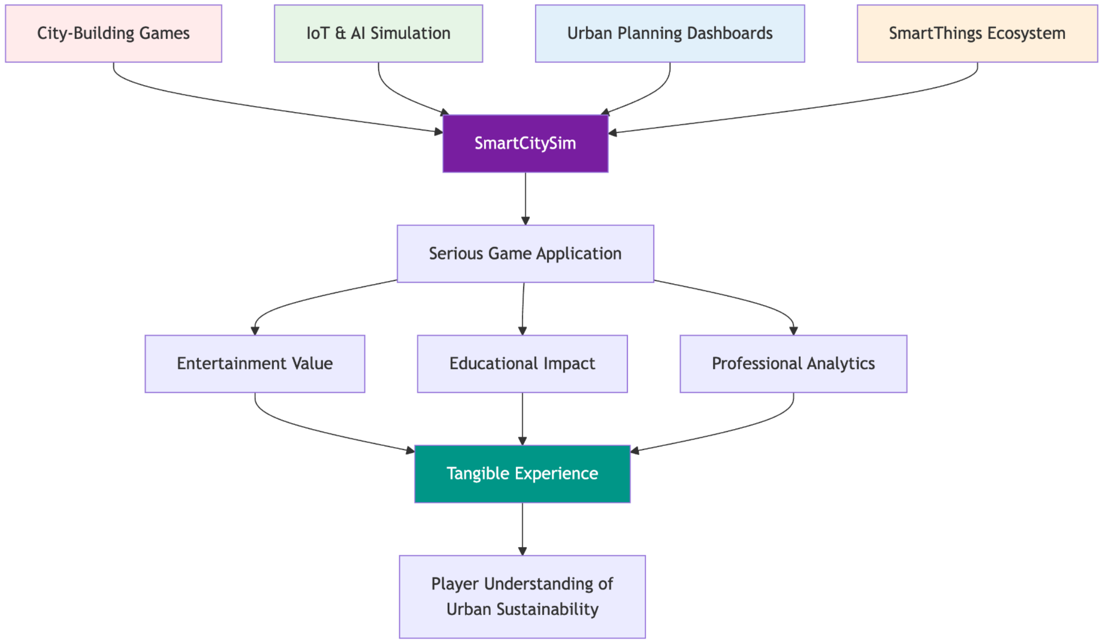
The game integrates **data-driven dashboards** with an **interactive city builder**:

- **Game Layer:** Players place roads, buses, solar panels, and parks.

- **Simulation Layer:** Predictive models estimate sustainability metrics.

- **IoT Tie-In:** A SmartThings-inspired system simulates how **household-level actions** (e.g., reducing home energy use) scale to **city-wide impact**.

By uniting **AI/ML, IoT concepts, and gamification**, SmartCitySim both **educates players** and **demonstrates smart city platform potential**, aligning with initiatives from **Samsung SDS & Samsung C&T**. Players build and manage a sustainable city where every planning decision dynamically impacts real-time traffic, CO_2 emissions, and energy consumption through an AI-powered simulation backend.



See Figure 2: System Architecture Diagram

Motivation & Problem Statement

Context: Urban areas face escalating **traffic congestion, climate change, and energy inefficiency**. While **smart city platforms** exist, citizens often lack **engaging tools** to understand the **consequences of their choices**.

Problem: Current smart city dashboards are **technical** and not designed for citizen engagement. Games like *SimCity* are **engaging**, but **lack real-world sustainability integration**.

Solution: SmartCitySim bridges this gap by merging **serious data dashboards** with **playful, Sims-like city-building**. It makes **sustainability trade-offs visible** and **interactive**, motivating both **learning** and **behavioral awareness**.

Impact:

- **Education:** Helps users understand trade-offs between transport, climate, and livability.
- **Research:** Serves as a prototype for integrating **IoT + AI + gamification** in urban planning.
- **Industry Alignment:** Matches smart city R&D focus areas of Samsung SDS and related organizations.

Target Audience and Personas

Primary Users:

- **Students & Citizens**: Learn sustainability through gamified simulation.
- **Gamers:** Fans of *SimCity* and *management sims*.
- **Policy Students:** Use tool for urban planning scenarios.

Secondary Users:

- **Smart City Researchers:** Prototype for Samsung SDS, government agencies.
- **Educators:** Classroom tool for sustainability awareness.

Personas:

- **Student Planner (Age 21):** Wants hands-on sustainability training.
- **Eco-Gamer (Age 25–35):** Enjoys simulations, experiments with CO_2 reduction strategies.
- **Analyst (Age 30+):** Uses tool to demo IoT + energy-saving effects on cities.

Gameplay / User Journey Scenarios

Traffic Optimization: Player adds buses → congestion & CO_2 drop.

Flood Resilience: Player builds parks → flood risk decreases, happiness rises.

IoT Household Action: Player reduces household energy via SmartThings → CO_2 reduction city-wide.

Trade-Offs: Building solar farms cuts emissions but costs resources → players must balance.

Scenario 1: The Commuter Crisis

- Story: "Rush hour gridlock is choking the city! Citizens are frustrated and emissions are soaring."
- Goal: Reduce traffic congestion by 50% within 7 days (game time)
- Tools: Bus routes, subway lines, bike lanes, traffic light optimization
- Strategy: Balance infrastructure costs vs. congestion relief; use IoT smart traffic systems

Scenario 2: The Green Mandate

- Story: "New environmental regulations require CO_2 neutrality by 2030. Can you transform the city in time?"
- Goal: Achieve 40% CO_2 reduction while maintaining 70% citizen happiness
- Tools: Solar farms, EV charging stations, green buildings, park systems
- Strategy: Phase out coal plants gradually while expanding renewables

Scenario 3: Climate Resilience

- Story: "Extreme weather events are increasing. Build a city that can withstand floods and heatwaves."
- Goal: Maintain 80% operational capacity during simulated disasters
- Tools: Flood barriers, green roofs, emergency services, backup power
- Strategy: Invest in prevention vs. reaction; balance resilience budget

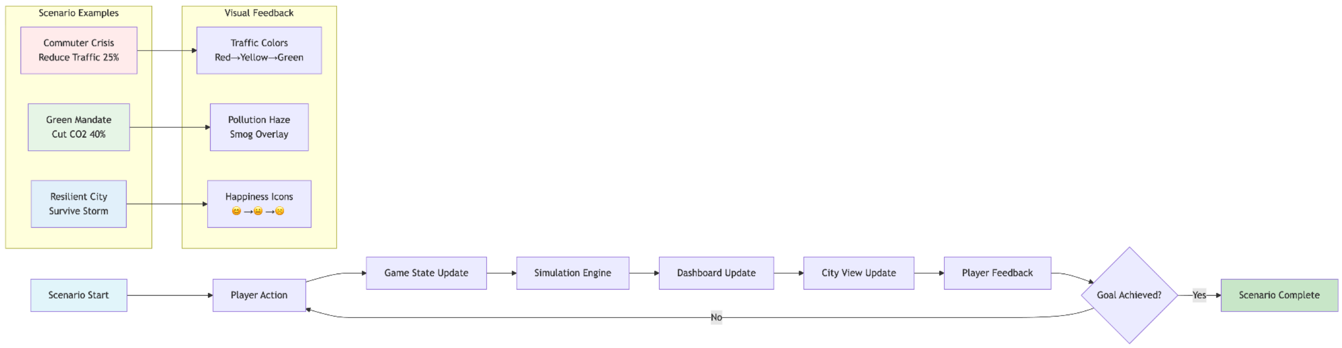


Figure 3: Scenario Gameplay Flow Diagram

Daily Gameplay Loop (Example Session)

Morning Session (15-20 minutes):

1. Dashboard Check: "Traffic at 75% - critical congestion in downtown"
2. Problem ID: Heatmap shows highway interchange bottleneck
3. Solutions: Add express bus lane + optimize traffic light timing
4. Impact: Traffic drops to 45%, CO_2 reduces by 8%, Happiness +5%
5. Learning: "Dedicated transit corridors solve congestion efficiently"

Core Features Overview

7.1 City Builder Mechanics

Tile-based city grid (roads, buildings, green spaces).

Place, upgrade, demolish infrastructure.

Citizens & vehicles simulated as agents.

7.2 Sustainability Metrics Dashboard

Metrics: **Traffic, CO_2, Energy, Flood Risk, Happiness**.

Heatmaps + graphs for real-time visualization.

7.3 Traffic & Energy Simulation

Rules-based for baseline.

ML models for predictions (traffic congestion, emission curves).

7.4 SmartThings IoT Tie-In

Simulated IoT device scaling.

Example: “Turn off 10,000 AC units → -2% CO_2 emissions.”

7.5 Gamification

Happiness Meter.

Unlockable upgrades: EV stations, bike lanes.

Leaderboard: Compare sustainability performance.

7.6 Core Gameplay Loop (30-60 seconds)

Observe → Decide → Build → Simulate → Learn

• Check real-time metrics dashboard

• Identify problem areas via heatmaps

• Place/adjust infrastructure

• Trigger IoT smart actions

• See immediate visual feedback

• Understand cause-effect relationships

7.7 Meta Progression Systems

- Building Unlocks: Basic roads → Smart highways → EV networks
- IoT Features: Simple alerts → Automation rules → Predictive optimization
- Data Analytics: Basic metrics → Predictive insights → AI recommendations
- Scenario Difficulty: Single objectives → Multi-objective optimization

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User Interface (UI) & Accessibility

Two Views:

Gamified City View (tilemap city builder).

Professional Dashboard View (charts, heatmaps).

UI Principles:

High-contrast visuals.

Clear color-coded sustainability indicators.

Simple interaction flow: build → see impact.

System Architecture

9.1 Unity Frontend (Tilemap & Agents)

Tile-based 2D/3D city grid.

Agent-based cars/citizens.

9.2 Backend Simulation & ML API

Framework: Python Flask REST API.

Function: Receives city layout JSON, returns simulation results.

Scalability: Designed for potential migration to FastAPI for enhanced performance.

9.3 Database (PostgreSQL/PostGIS + Redis)

Stores layouts, simulations, metrics.

Redis cache for performance.

9.4 IoT Simulation Layer

Mock SmartThings API.

Household → district → city scaling model.

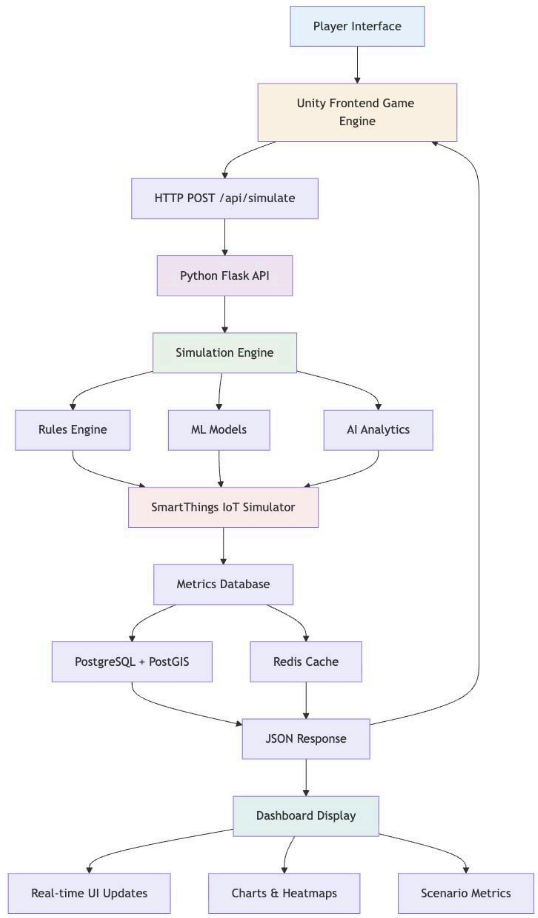

Figure 4: System Architecture Overview

Machine Learning Architecture

10.1 Rules-Based Baseline

Example: +100 buses = -5% congestion.

10.2 Predictive ML Models

Regression & LSTMs for congestion & emissions.

Synthetic + open datasets (Seoul Open Data, OSM).

10.3 Fusion Pipeline

Ensemble: traffic + energy + climate.

Outputs combined sustainability score.

10.4 Model Selection Strategy

Scikit-learn: Linear regression, decision trees for baseline models

TensorFlow/Keras: LSTM networks for time-series traffic prediction

PyTorch: Custom neural networks for complex urban simulations

Ensemble approach:Combine simple and complex models for robustness

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App Modules & Data Flow

Flow:
Unity Client → Backend API → ML Engine → Metrics DB → Unity/Dashboard UI.

Modules:

Tilemap Editor (city building).

Agent Simulation (traffic flow).

ML Prediction Engine.

Dashboard Visualization.

User Interface

Player Experience Journey

- Early Game: "How do buildings affect my city?" (Learn basic cause-effect)
- Mid Game: "How do I balance growth vs sustainability?" (Master trade-offs)
- Late Game: "Can I optimize everything with IoT automation?" (Achieve mastery)

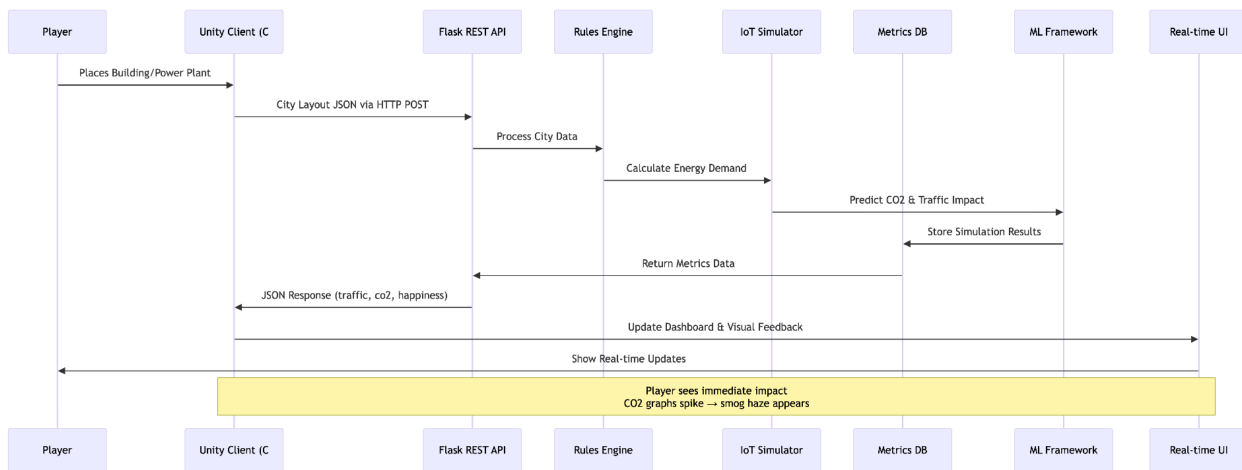

Figure 5: Real-time Implementation Sequence

Development Roadmap (12-Month)

MVP Path (Weeks 1–12):

Week 1-3: Unity Foundation

- Tilemap system implementation
- Basic UI framework and navigation
- Building placement/demolition mechanics
- Camera controls and grid system

Week 4-5: Backend API + Rules Simulation

- Flask REST API setup and endpoints
- Basic traffic simulation (rules-based)
- CO_2 emission calculation models
- JSON data exchange protocol

Week 6-7: Dashboard Integration + Real-time Metrics

- Sustainability dashboard UI
- Real-time metrics visualization
- Heatmap system for problem areas
- Basic chart and graph components

Week 8: First Playable Loop + Basic IoT Mock Actions

- Complete build → simulate → feedback loop
- "Eco-Mode" IoT mock action implementation
- Basic cause-effect relationships visible
- Minimum viable gameplay experience

Week 9-10: Agent System & Citizen Behavior

- Citizen agent AI and pathfinding
- Vehicle traffic simulation
- Basic happiness calculation
- Visual feedback (emojis, animations)

Week 11: Progression Systems & Scenarios

- First scenario mission: "Commuter Crisis"
- Building unlock system
- Basic achievement tracking
- Win/lose condition implementation

Week 12: MVP Polish & Testing

- Bug fixing and performance optimization
- UI/UX refinements
- Internal alpha testing (5 testers)
- MVP documentation and demo preparation

Advanced ML Path (Weeks 13–24):

Week 13-15: ML Traffic Prediction

- LSTM model for traffic congestion forecasting
- Integration with existing traffic simulation
- Model training and validation pipeline

Week 16-18: Energy & Climate Models

- Renewable energy simulation models
- CO_2 prediction algorithms
- Flood risk assessment system

Week 19-21: Advanced IoT Integration

- SmartThings API simulation scaling
- Household-to-city impact modeling
- Automation rule system

Week 22-24: Ensemble Pipeline & Analytics

- Multi-model ensemble fusion
- Predictive sustainability scoring
- Advanced analytics dashboard
- ML model performance optimization

Final Phase (Weeks 25–26):

Week 25: Usability Testing & Refinement

- External user testing (10-15 participants)
- Feedback collection and analysis
- Gameplay balancing and tuning

Week 26: Final Polish & Deployment

- UI/UX final polish
- Performance optimization
- Final demo build preparation
- Capstone report completion and submission

Testing & Validation Plan

13.1 Usability Testing:

Recruit 5–10 players.

Evaluate clarity of dashboard/game link.

13.2 Simulation Benchmarking:

Compare congestion predictions with open datasets.

13.3 Offline Robustness:

Test Unity-client demo mode without backend.

13.4 Success Metrics & Player Validation

Win Conditions:

- Traffic congestion < 50%
- CO_2 emissions < 40% of baseline
- Citizen happiness > 80%
- Energy sustainability > 75%

Player Success Signals:

- "Aha!" moments when micro-actions create macro-impact
- Visible heatmap changes (red → yellow → green)
- Leaderboard progression and achievement unlocks
- Demonstrated understanding of sustainability trade-offs

Technology Stack & Platforms

Frontend (Game): Unity (C#) with Tilemap system for city building.

Backend: Python Flask with REST API + Machine Learning models.

Database: PostgreSQL + PostGIS (spatial data), Redis (caching).

Simulation: Hybrid rules-based + ML predictive models.

ML: TensorFlow/Keras or PyTorch.

Deployment: Docker containerization, AWS/Azure cloud deployment.

IoT Integration: SmartThings-inspired simulated API.

Budget & Resource Planning

Resource	Cost (USD)	Justification
Unity Assets	$150	Tilemaps, models.
Datasets	Free	Open data portals.
Cloud Hosting	$100	Backend deployment.
Dev Licenses	$25	GitHub Student/Play Store.
Contingency	$200	Unexpected costs.

Total Estimate: ~$475

Risk Management

Data Gaps: Use synthetic data if real unavailable.

Performance Issues: Optimize with Redis caching.

Over-Complex Scope: MVP first, ML later.

Integration Risks: SmartThings tie-in simulated, not live.

Appendices

A. Diagrams:

System architecture diagram.

ML pipeline flow.

Roadmap Gantt chart.

B. Sample Data:

Seoul traffic dataset.

Synthetic CO_2 reduction samples.

C. External References:

OSM, Seoul Open Data, IPCC emission factors.

D. Usability Study Protocol:

Playtest feedback forms.

Performance benchmarks.

E. Progression Systems Detail

Building unlock trees with prerequisites

IoT feature progression path

Scenario difficulty scaling curves

Player skill development milestones

F. Player Experience Examples

"Player A (Student): Started confused about bus routes → After 3 sessions, optimized entire transit network"
"Player B (Gamer): Initially focused on aesthetics → Learned to balance beauty vs. functionality"

G: Success Moments Catalog

"Players feel brilliant when their park placement solves both happiness AND flood risk"

"The 'IoT automation unlock' creates visible efficiency leaps on dashboard"

"Leaderboard competition drives optimization creativity"

H: Research Ethics & Data Collection

Participant consent forms template

Data anonymization procedures

IRB approval documentation outline

I: Publication Opportunities

Conference targets: CHI PLAY, IEEE Games Entertainment Media

Journal targets: Simulation & Gaming, Sustainable Cities and Society

University showcase events and dates

Research Contribution & Evaluation Metrics

14.1 Academic Research Questions:

1. Does gamification improve understanding of urban sustainability trade-offs?
2. Can AI simulation accurately predict city-scale impacts of planning decisions?
3. How effective is IoT concept integration in educational gaming?

14.2 Evaluation Methodology:

Pre/post-test surveys measuring sustainability knowledge

Gameplay analytics tracking decision-making patterns

Focus groups discussing learning outcomes

14.3 Expected Contributions:

Novel framework for serious games in urban planning education

ML integration model for real-time city simulation

Validation of gamified IoT concept understanding

14.4 Expected Impact:

Academic: New framework for AI-enhanced serious games

Industry: Prototype for citizen engagement in smart city planning

Educational: Scalable tool for sustainability curriculum enhancement

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Theoretical Framework

15.1 Knowledge Gap Identification

Current Limitations: Traditional urban planning tools lack engagement; commercial games lack real-world accuracy

Research Void: Limited integration of predictive AI with gamified sustainability education

Theoretical Basis: Constructivist learning theory + situated learning in simulated environments

15.2 Original Contribution Matrix

Domain	***Current State***	***SmartCitySim Innovation***
Game-Based Learning	Simple cause-effect	Dynamic AI simulation with real-time feedback
Urban Planning Tools	Static dashboards	Interactive scenario missions with trade-offs
IoT Education	Technical documentation	Gamified household-to-city scaling

AI Integration	Offline analytics	Live predictive models in gameplay loop

15.3 Comparative Analysis & Research Positioning

Industry & Academic Landscape Analysis

Current systems either provide engaging gameplay without real-world accuracy (commercial games) or accurate simulations without engagement (academic tools). SmartCitySim bridges this gap through real-time AI integration.

Research Gap Identification

Verified Through Systematic Analysis:

- ACM Digital Library Search: "real-time ML + city-building game" = 0 results
- IEEE Xplore Search: "ensemble AI + sustainability game" = 2 results (neither interactive)
- Google Scholar: "IoT scaling + educational game" = Limited to technical simulations

Confirmed Original Contribution:
"No published work combines all four elements: (1) real-time ensemble ML prediction, (2) interactive city-building gameplay, (3) household-to-city IoT scaling, (4) sustainability education focus."

Research Gap Confirmation:

Systematic literature review confirms no existing work combines real-time ensemble ML prediction with interactive city-building gameplay for sustainability education. This positions SmartCitySim as filling a meaningful gap in both gaming and urban informatics research.