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Research Article

From Games to Smart Cities: How Game Engine Technology Became the Backbone of Urban Digital Twins?

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Abstract

This paper investigates the accelerating convergence between the game design industry and the smart city digital twin platforms that are governing the world's most complex urban environments (Deng et al., 2021, Abdelrahman et al., 2025). Building directly upon prior empirical work examining Shanghai's city-scale digital twin implementation (Najafi, 2025) and the multi-scalar Urban Operating System (Urban OS) framework (Najafi, 2026), this research traces the technological genealogy linking game engines, procedural generation, AI-driven agent simulation, and photorealistic rendering to real-time urban management platforms. The paper demonstrates that this convergence is not coincidental co-evolution but a deliberate and productive cross-pollination: game engines such as Unreal Engine 5 and NVIDIA Omniverse, originally optimised for entertainment, have become the backbone of city-scale digital twins across Shanghai, Singapore, Dubai, Riyadh and many other cities around the world. Conversely, the demand for high-fidelity urban simulation is driving innovations back into the gaming sector, enriching open-world and city-building genres with unprecedented authenticity. Through a synthesis of empirical cases, expert frameworks, and current scholarship, this study identifies five critical technology transfer vectors (rendering pipelines, physics simulation, AI agent systems, procedural generation, and collaborative networking) as the structural bridges connecting these two worlds and proposes the Game-City Continuum as a conceptual framework for understanding this symbiosis in contemporary smart urban governance.

Keywords: Smart cities; Digital Twins; Game engines; Urban planning; Urban operating system; Real-time rendering.

Highlights

- Game engine technologies originally built for entertainment now power real-time governance of megacities.
- The Game-City Continuum maps how fidelity, agency, and connectivity bridge virtual worlds and urban twins.
- Adopting game-derived platforms without critical reflection risks encoding algorithmic bias into governance.

1 Introduction

The same software engine used to render the neon-lit streets of a cyberpunk metropolis in a video game can now simulate traffic flows, flood risk, and wind turbulence across a real megacity of 24 million people like Shanghai (Figure 1). This convergence, between the entertainment industry's relentless pursuit of visual and behavioural fidelity in virtual worlds and the urban planning profession's growing need for high-fidelity, real-time urban representations, is one of the most consequential technology transfers.

Figure 1. The Digital Twin Urban Operating System architecture illustrating how raw sensor inputs transform through Sensing, Integration, Simulation, and Interaction layers into actionable urban intelligence. This four-layer framework, built on Unreal Engine technology, mirrors the architecture of complex game world systems. Image courtesy of 51World, used with permission (Najafi, 2026).

Najafi (2025) examined Shanghai's pioneering city-scale digital twin through the groundbreaking works of Beijing based company, 51World, and their Earth Clone platform, documenting the technical architecture, governance challenges, and transformative potential of photorealistic urban simulation at the scale of 3,750 km^2. Najafi (2026) extended this research into a generic, multi-scalar Urban Operating System (Urban OS) framework, validated through comparative analysis of implementations in Shanghai, Singapore, Dubai, Riyadh, and Osmaniye, and engaging with governance standards from the World Economic Forum and the International Telecommunication Union. These two studies observe that the rendering engines, simulation pipelines, and interactive frameworks powering these urban platforms were not initially developed for cities, they were developed for games.

The present paper interrogates this observation in depth. It asks: how has the game design and entertainment industry contributed to the development of smart city digital twins? What specific technologies, conceptual frameworks, and design philosophies have migrated from entertainment to urban governance? And what does this cross-disciplinary flow portend for the future of city planning, citizen engagement, and urban resilience? The paper also examines the reverse flow, the ways in which the demands of urban simulation are enriching the gaming industry, arguing that this constitutes a genuine bidirectional symbiosis rather than a one-way transfer.

The scope of this inquiry is both timely. The global digital twin market was projected to grow from $24.48 billion in 2025 to $259.32 billion by 2032 at a compound annual growth rate of 40.1% (Program-Ace, 2025), while the AI in gaming market alone was forecast to expand from $3.28 billion in 2024 to over $51 billion by 2033 (Capitol Technology University, 2026). These parallel trajectories show dependency.

2 Methodology

This paper adopts a qualitative, multi-method research design grounded in systematic literature synthesis, empirical case analysis, and conceptual framework development. The literature review draws on peer-reviewed publications, technical documentation, and industry reports spanning urban informatics, game studies, computer graphics, and smart city governance, sourced through targeted database searches covering the period 1956 to 2026, with particular attention to seminal works in procedural generation, physics simulation, and real-time rendering that establish the historical lineage of technology transfer. Empirical grounding is provided through in-depth case analysis of four operational urban digital twin deployments, specifically Shanghai, Singapore, Dubai, and Riyadh, selected on the criteria of scale, documented technical architecture, and governance maturity, with primary technical data drawn from the author's prior fieldwork and platform access through 51World (Najafi, 2025, 2026). Cross-case comparison follows a structured analytical protocol examining each deployment against five technology transfer vectors, namely rendering pipelines, physics engines, AI agent systems, procedural generation, and collaborative networking, to assess the degree and directionality of convergence between game engine and urban governance applications. The conceptual framework, the Game-City Continuum, is developed inductively from patterns identified across the case evidence and validated deductively against the governance frameworks of the World Economic Forum (2022) and the ITU (2025), ensuring the framework reflects both empirical observation and established normative standards in the field.

3 Urban Simulation in the Gaming Tradition

The idea of simulating a city in a computer predates digital twins, smart cities, and even the internet. In 1969, urban systems theorist Jay Forrester published *Urban Dynamics*, a computational model treating metropolitan areas as systems of interacting variables (population, industry, housing, etc.) that could be mechanically steered by planners (Simon, 2020). Forrester's framework was controversial, but it planted the seed of an idea: that the complexity of urban life could be captured, compressed, and experimented with in a virtual model.

That seed germinated most prolifically not in academia, but in entertainment. In 1989, game designer Will Wright released SimCity (Figure 2), in which players became mayors, zoning land, building infrastructure, managing budgets, and watching virtual populations respond (Simon, 2020). The game was initially rejected by publishers who could not understand why anyone would play something without a victory condition. They were wrong. SimCity became a cultural phenomenon and, more significantly, an instrument of genuine urban education.

Gaber (2007) argued it achieved systemic urban thinking better than many conventional pedagogical tools, and a generation of urban planners have reported being inspired to enter the profession by the game. The game's mechanics encoded concepts such as land use compatibility, pollution externalities, the economics of density, and proximity-based service provision, what urban theorists would later formalise as the *15-minute city* (Shi et al., 2024).

The popular game *Cities: Skylines* (2015) extended this tradition significantly, offering genuine planning complexity which includes traffic modelling, zoning nuance, and a modifiable codebase allowing players to import real-world geographic data (Szot, 2024). Academic researchers began using it as a teaching tool for sustainability and urban geography (Jolly & Budke, 2023), and planning professionals noted its value for conceptual iteration. Researchers at Bloomberg noted that *Cities: Skylines* (Figure 3) had been acknowledged as an inspiration for Singapore's national digital twin (Poon, 2022).

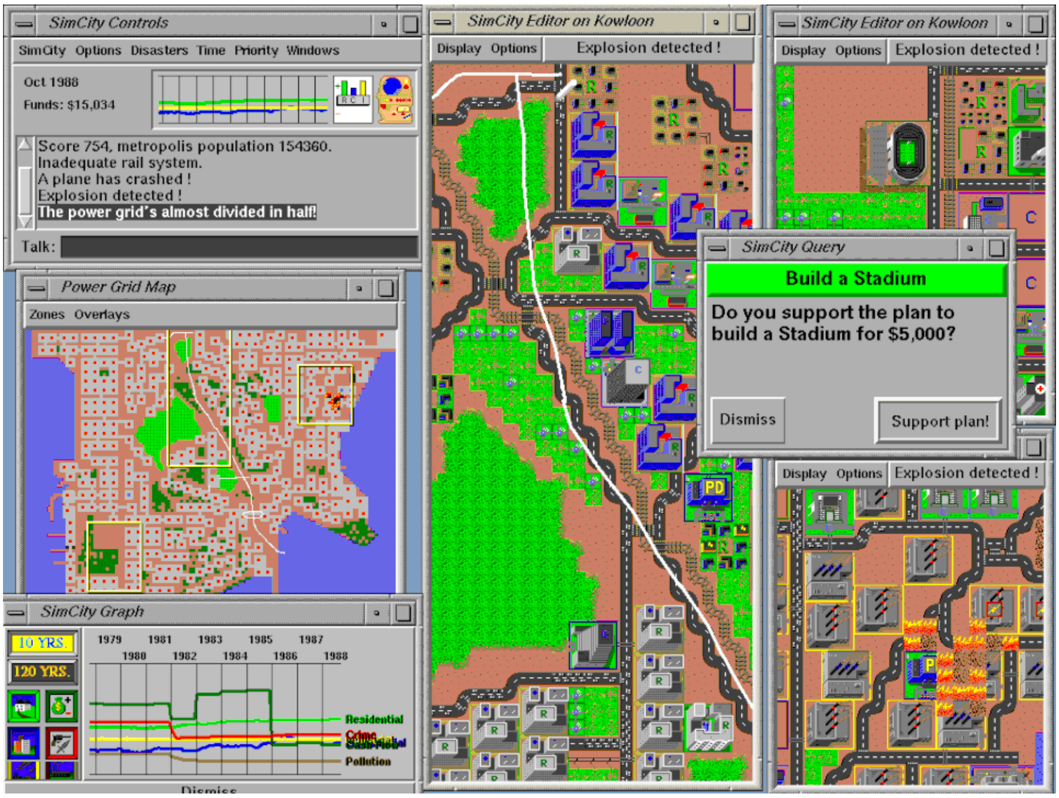

Figure 2. The 1989 SimCity on SGI Indigo workstation. Wikimedia Commons (public domain). Retrieved from https://commons.wikimedia.org/wiki/File:SimCity-Indigo.gif

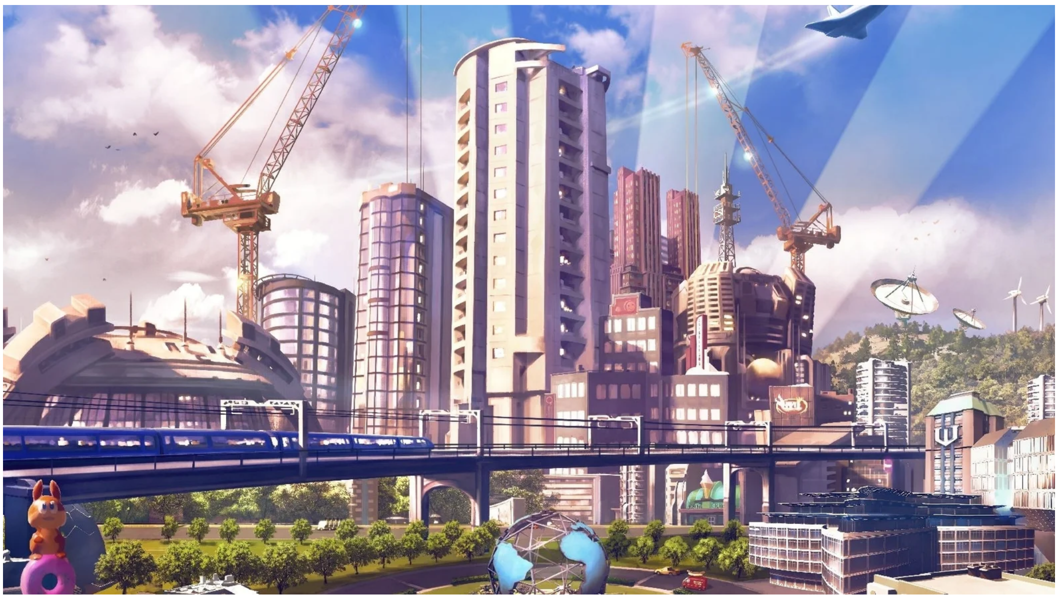

Figure 3. Cities: Skylines screenshot, Ubisoft (2015). Note. From "Acclaimed city builder Cities: Skylines is free to play this weekend on Steam," by Eurogamer, 2020. Screenshot reproduced with permission. https://www.eurogamer.net/acclaimed-city-builder-cities-skylines-is-free-to-play-this-weekend-on-steam

These games were abstractions, simplified models that sacrificed accuracy for playability. But they did something arguably more important: they normalised urban simulation, cultivated a generation of planners fluent in digital spatial reasoning, and created mass market demand for ever more realistic virtual environments (Deren, 2021). That demand drove the very technological developments, game engine advances in rendering, physics, and AI, that eventually made photorealistic city-scale digital twins possible (Li, 2024).

4 Five Vectors of Technology Transfer

The transition from traditional Geographic Information Systems (GIS) to Game-Engine-driven Digital Twins marks more than a mere upgrade in rendering capability; it represents a profound ontological convergence between the simulated and the physical. In this paradigm, the city is no longer viewed merely as a static collection of physical assets to be mapped, but as a dynamic, interactive *level* to be programmed (Wu, 2023). By importing high-fidelity urban data into environments such as Unreal Engine 5 or NVIDIA Omniverse, planners are effectively re-categorising urban elements (infrastructure, flora, and residents) as *Actors* or *Objects* within a computational hierarchy (Najafi, 2026).

This shift imposes a specific object-oriented logic on urban reality. In a game engine, every entity is defined by its properties, functions, and its capacity to interact with other *Actors*. When applied to a Smart City, this allows for unprecedented simulation depth, but it also invites a critical theoretical challenge often described as the SimCity Effect (Mitchell, 2015). This effect refers to a form of algorithmic reductionism where the *messiness* of human sociology and the spontaneity of urban life are flattened into NPC (Non-Player Character) logic.

In this arena, the clearest example is Unreal Engine, developed by Epic Games. Originally released in 1998 as a first-person shooter engine, it has evolved into what Epic now describes as a *real-time 3D creation platform* for industries from film to automotive design to urban planning (Epic Games, 2024, 2025). Its application in urban digital twins accelerated dramatically with the release of Unreal Engine 5 in 2022, introducing Nanite, a virtualised geometry system rendering scenes containing billions of polygons without manual level-of-detail configuration, and Lumen, a fully dynamic global illumination system producing cinematically realistic lighting in real time. These capabilities, designed to create immersive game worlds, proved precisely what urban digital twins required: handling the staggering geometric complexity of a real city while maintaining interactive frame rates.

In a parallel attempt, NVIDIA's Omniverse platform represents a similar trajectory. In November 2024, NVIDIA announced an Omniverse Blueprint enabling real-time physics-based digital twins, combining CUDA-X acceleration libraries, the PhysicsNemo physics-AI framework, and RTX-enabled visualisation to achieve simulations up to 1,200 times faster than conventional approaches (NVIDIA, 2024).

4.1 Rendering and Level-of-Detail Management

City-scale digital twins face the same fundamental challenge that open-world game designers have grappled with for decades: how to represent a vast, geometrically complex environment at interactive frame rates without overwhelming GPU memory or processing capacity. A photorealistic model of a single city block may contain millions of polygons; a city of several thousand square kilometres contains billions. Rendering every polygon in every building simultaneously is computationally impossible in real time, yet the illusion of seamless, navigable urban space depends on users never perceiving this constraint. The solution the game industry developed, and which urban digital twin platforms have directly adopted, is the Level-of-Detail (LOD) system. In an LOD framework, every object in the scene exists not as a single mesh but as a family of meshes at progressively decreasing geometric resolution (Luebke et al., 2002). A detailed building model viewed up close might be represented by a high-polygon mesh capturing every architectural feature, cornice, and window reveal. The same building viewed from two kilometres away is rendered using a simple box approximation with a photographic texture applied to its surface. At ten kilometres, it may be represented by a single flat billboard oriented toward the camera. The rendering engine constantly calculates each object's distance and importance and dynamically swaps between these representations, serving the most detailed version only when computational resources are justified by proximity. The result is that the viewer perceives continuous photorealistic space while the GPU is, in fact, rendering a carefully managed hierarchy of approximations.

In the case of Shanghai's digital twin by 51 World company, the immense spatial scale of Shanghai necessitates advanced strategies for managing detail and data streaming. To address this, the urban environment is segmented into tiles measuring approximately 2 x 2 kilometres, which are dynamically loaded or unloaded according to the viewer's proximity and available system resources (Figure 4). This approach relies on quadtree-based spatial indexing, a technique adapted from real-time graphics and game development, allowing the system to maintain stable performance across multiple viewing scales, from broad metropolitan perspectives to fine-grained street-level visualization.

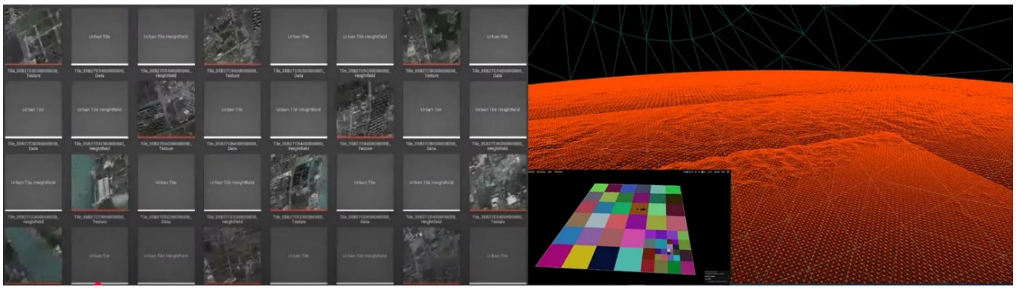

Figure 4. Tile-based streaming framework illustrating the 2 x 2 km grid used to organise Shanghai's extensive spatial dataset. Colour coding represents loading priority determined by camera location and viewing direction, helping regulate memory allocation and rendering efficiency (image courtesy of 51World, used with permission).

According to its Earth Cloning development roadmap, 51World has progressively advanced from static digital representations toward dynamic, semi-simulated environments and, from around 2023 onward, toward fully simulated worlds. These developments aim to support real-time world generation, semantics-driven content creation, and runtime modification through Unreal Engine 5 technologies such as Nanite, Lumen, and high-precision coordinate systems (Mills, 2020). Management of terrain, vegetation, and ecological components is achieved through a hierarchical pyramid or quadtree framework that governs terrain Level-of-Detail scheduling and content culling. As viewing distance increases, simplified geometry and lower-resolution textures are substituted, while closer perspectives trigger the loading and rendering of more detailed models (Figure 5).

In another case, Singapore's Virtual Singapore national twin, as documented by Najafi (2026), explicitly organises its urban model around LOD levels ranging from LOD 1 (simple massing blocks representing building footprints and heights) through to LOD 3 and LOD 4 (models incorporating facade detail, interior spaces, structural components, and subterranean infrastructure). Different city districts are modelled at different LOD levels depending on governance priorities, with critical infrastructure zones receiving the highest-resolution treatment and peripheral areas rendered at lower fidelity, a resource allocation strategy identical in logic to what game designers call *streaming zones*. 51World's proprietary taxonomy extends this to five levels (L1-L5), corresponding to progressively richer data integration from basic massing geometry at L1 to fully interior-modelled, BIM-integrated structures at L5 (Najafi, 2026). The revolutionary contribution of Unreal Engine 5's Nanite technology lies in its elimination of the manual LOD configuration burden that had previously required teams of 3D artists to produce and validate every level of every asset. Nanite implements a virtualised geometry system in which the engine automatically derives the appropriate level of geometric approximation for any object at any distance in real time, processing scenes containing effectively unlimited polygon counts without artist intervention. For urban digital twin operators like 51World, whose city models must incorporate millions of individually distinct structures, this automation is transformative: it makes photographic fidelity at city scale computationally tractable and is central to the platform's ability to render the full 3,750 km^2 of Shanghai with the visual density of a AAA video game (Najafi, 2025). The game industry's parallel development of streaming architectures, which load and unload scene geometry dynamically as the virtual camera moves, rather than holding an entire city in GPU memory simultaneously, provides the complementary mechanism. These GPU-accelerated rendering pipelines and streaming systems are all directly echoed in the interaction layer of modern Urban OS platforms (Najafi, 2026), making the boundary between a game engine's scene management system and an urban digital twin's visualisation layer technically indistinct.

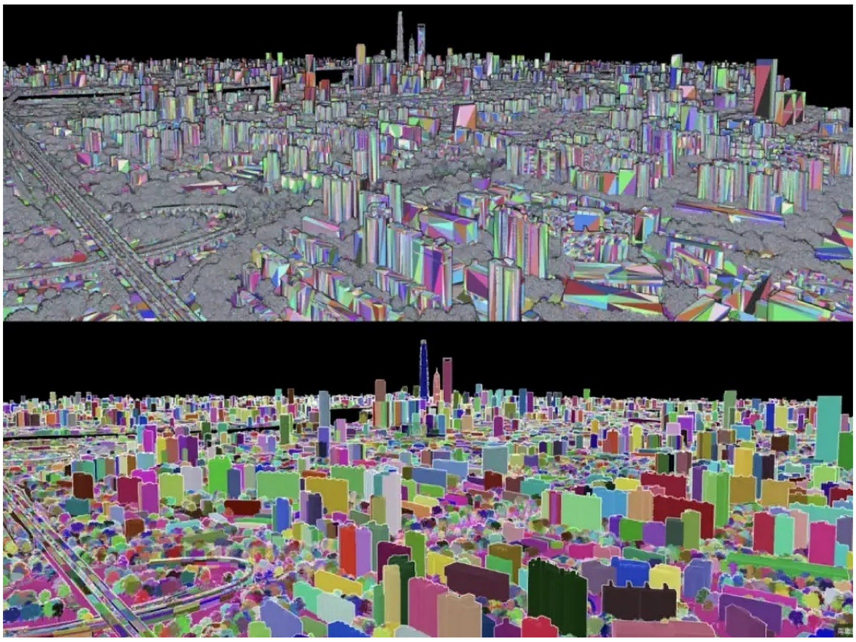

Figure 5. Hierarchical Level-of-Detail (LOD) representation showing the gradual increase in geometric complexity and texture fidelity as the viewer moves closer to the scene, supporting efficient rendering across a wide range of spatial scales (image courtesy of 51World, used with permission).

4.2 Physics Engines and Environmental Simulation

The physics simulation capabilities deployed in urban digital twin platforms originate in engineering and applied mathematics and were later adopted independently by both the game industry and the urban simulation sector, each for its own purposes and with its own trade-offs. The intellectual foundation is the Finite Element Method (FEM), formalised by Turner, Clough, Martin, and Topp in their landmark 1956 paper, "Stiffness and Deflection Analysis of Complex Structures," developed at Boeing and UC Berkeley to solve structural problems in aircraft design that physical prototyping alone could not address (Turner et al., 1956). In a paper published in 1960, Ray Clough coined the term Finite Element Method, and the method generalised rapidly across engineering disciplines including structural analysis, heat transfer, fluid dynamics, and electromagnetism, driven by parallel advances in computing power (Clough, 1990). By the 1960s and 1970s, FEM-based simulation had become the standard tool for structural integrity assessment in aerospace, civil infrastructure, and nuclear engineering; NASA developed NASTRAN, its own FEM code, in 1965, and commercial codes such as ANSYS followed shortly after.

High-precision physics engines, as opposed to the real-time engines that games would later adopt, require more processing power to calculate very precise physics and are used by scientists and computer-animated movies, while real-time engines use simplified calculations and decreased accuracy to compute in time for the game loop. This distinction is the essential one for understanding the relationship between the three domains of engineering simulation, game physics, and urban digital twins. When the game industry began incorporating physics into interactive environments from the late 1990s onward, it did not develop new physics; it strategically approximated existing engineering science. Physics simulators can be classified into two main groups: scientific simulators, which focus on the accuracy of the simulation regardless of computational time, and real-time simulators or physics engines, which aim at computing as fast as possible by simplifying the underlying mathematical model, a loss of accuracy that is tolerable in games but would become a relevant problem in scientific applications. The Havok engine, first released in 2000, provided real-time collision and dynamics of rigid bodies in three dimensions, along with multiple types of dynamic constraints between rigid bodies, and a highly optimised collision detection library, all approximations of Newtonian mechanics that structural engineers had been computing with far greater rigour for decades. NVIDIA's PhysX engine extended this into fluid dynamics and particle systems, and Jos Stam's (2003) paper, *Real-Time Fluid Dynamics for Games*, made the epistemological contract of game physics explicit: its solvers were deliberately designed to sacrifice physical accuracy for unconditional stability and real-time speed.

Urban digital twins occupy a different and more complex position in this landscape, drawing simultaneously from both traditions rather than inheriting primarily from gaming. The physics simulation layer of a modern urban digital twin is not a single type of system but a multi-physics stack. Computational fluid dynamics (CFD) simulation, whether for wind flow around high-rise buildings, pollutant dispersion, or flood inundation, employs engineering-grade CFD solvers rooted in the Navier-Stokes equations, the same solvers used in aerospace and environmental science, running offline or on high-performance computing infrastructure before their outputs are rendered in real time. Structural health monitoring digital twins use streaming sensor data as external dynamic loads to reproduce the dynamic response of entire physical structures via finite-element-model-based digital twins, a direct transplantation of FEM from aerospace into urban infrastructure management. Seismic simulation in city digital twins similarly relies on established structural dynamics methods, such as elastic-plastic time history analysis, Rayleigh damping theory, and damage index modelling, to assess urban vulnerability during earthquake events (Yu et al., 2023). Thermal and energy simulation within urban twins applies building physics equations governing thermal conductivity and heat transfer to optimise HVAC systems and model urban heat islands (Omrany and Al-Obaidi, 2025). Acoustic simulation models noise propagation across urban districts for environmental planning. NVIDIA's Omniverse Blueprint framework, which powers some of the most advanced urban digital twin visualisation platforms, now explicitly supports coupled multi-physics workflows across domains including fluid and structure, radiation and convection, and airflow and acoustics, with leading engineering simulation vendors including Ansys, Siemens, and Cadence all integrated into the same platform.

What the game industry's contribution to this multi-physics stack actually consists of is the real-time visualisation and interactivity layer, the ability to render the outputs of engineering-grade simulations as navigable, photorealistic, interactive 3D environments at frame rates that city officials, planners, and emergency managers can engage with in real time. NVIDIA's PhysicsNemo framework, for instance, can accelerate CFD simulations up to 10,000 times faster than traditional methods by training physics-informed neural networks, with the resulting surrogate models then visualised interactively through Omniverse, a pipeline in which the physics is firmly engineering in origin, and the rendering and interactivity are firmly game-derived (Alamu et al., 2025). 51 World's Shanghai digital twin adopts the same concept to predict air quality dispersion, pedestrian comfort levels, and building thermal performance (Figure 6).

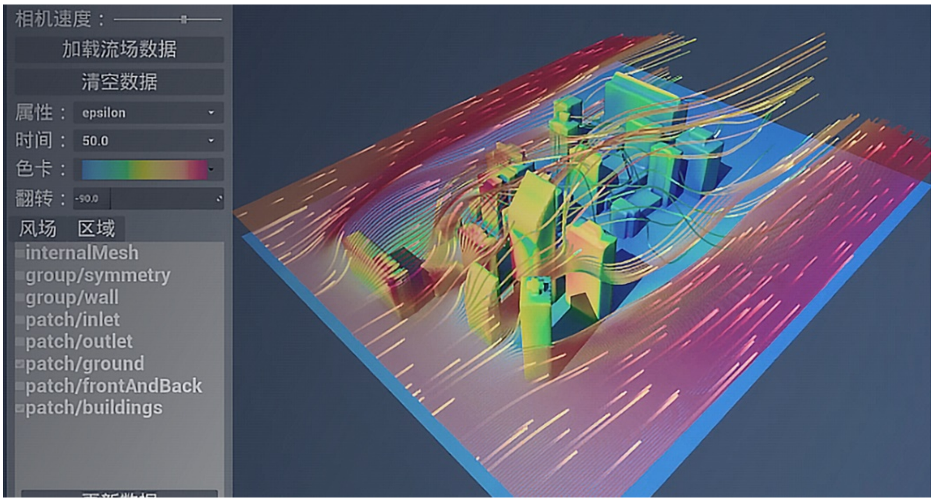

Figure 6. Computational Fluid Dynamics (CFD) visualisation of wind flow patterns around Shanghai's Pudong skyline, rendered in Unreal Engine with particle traces indicating air velocity and turbulence zones. This simulation capability, originating in game physics engines, now supports sustainable urban design by identifying wind corridors and air quality hotspots. Image courtesy of 51World, used with permission.

4.3 AI Agent Systems and Crowd Simulation

Modern video games simulate thousands of non-player characters (NPCs) using behaviour trees, pathfinding algorithms, and multi-agent scheduling systems that enable emergent crowd behaviour (Wang, 2024). The parallel to urban simulation is almost exact. The behaviour tree frameworks and pathfinding algorithms that game developers use to animate believable crowds are directly applied in urban simulation tools to model evacuation dynamics, event crowd management, and public transport boarding behaviour. For example, Unreal Engine 5's character agent systems are used, similar to those used for game NPCs, to simulate pedestrian traffic interactions in an Urban Digital Twin of Liverpool, Australia (Crampen et al., 2024). 51 World uses similar procedures to simulate human flow in urban structures and predict congestions and find the solutions for urban planning (Figure 7).

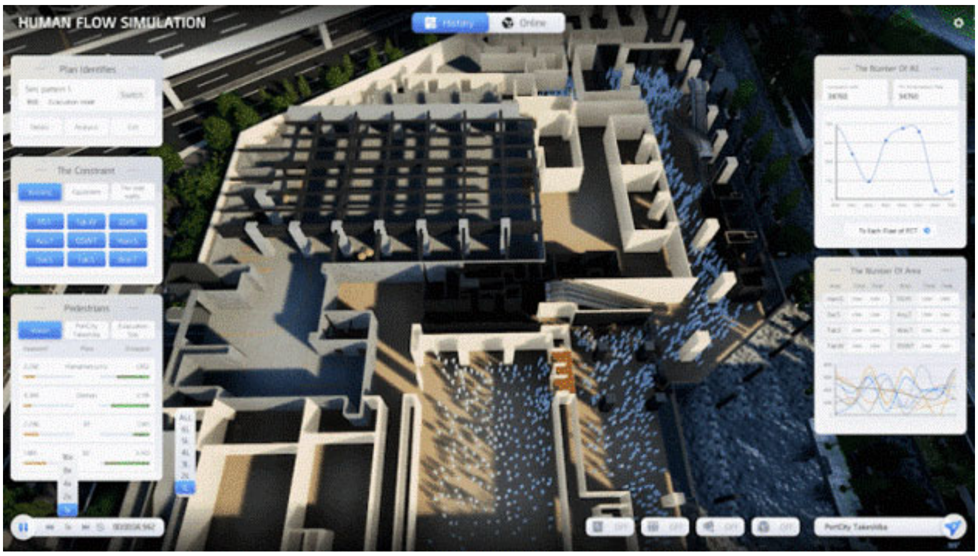

Figure 7. Human flow simulation in urban structures. Image courtesy of 51World, used with permission.

4.4 Procedural Generation and Automated City Modelling

Procedural content generation (PCG) is the use of algorithmic rules to automatically generate complex spatial content from a set of initial parameters and constraints. PCG has a longer academic genealogy than its association with games might suggest and tracing that genealogy is essential to understanding how it arrived in urban digital twin platforms. The mathematical foundation was laid by biologist Aristid Lindenmayer (1968) with his development of L-systems: formal string-rewriting grammars originally conceived to model the branching structure of plant cells, which Prusinkiewicz and Lindenmayer later (1990) extended into a comprehensive visual modelling framework. PCG in games is defined as the automatic or computer-assisted generation of content such as levels, landscapes, items, rules, and quests, and it was the game industry's adoption and refinement of L-systems and related grammatical approaches, for terrain generation, dungeon layouts, and foliage systems, that scaled these mathematical tools into practical, performance-optimised pipelines capable of generating geometrically complex environments in real time (Shaker et al., 2016). The games Rogue (1980) and Elite (1984) are commonly cited as the earliest commercial deployments of PCG for game level generation; over the following two decades, game developers systematically refined fractal terrain methods, and rule-based architecture generators to populate vast open worlds that no team of artists could have hand-authored at scale.

The critical pivot toward urban applications came at SIGGRAPH 2001, when Parish and Muller published their highly influential paper *Procedural Modeling of Cities*, which proposed a system using a procedural approach based on L-systems to model cities, generating from input maps of land-water boundaries and population density a complete system of highways and streets, dividing land into lots, and creating the appropriate building geometry for each allotment. This paper established the conceptual architecture that would directly underpin urban digital twin construction pipelines. Muller et al. (2006) later extended this work with their *Procedural Modeling of Buildings*, which introduced CGA shape, a novel shape grammar for computer-generated architecture, demonstrating that context-sensitive shape rules could produce building shells with high visual quality and geometric detail, generate extensive architectural models for computer games and movies at low cost, and efficiently produce massive urban models with unprecedented levels of detail, with the virtual rebuilding of Pompeii as its proof of concept. CGA shape directly became the engine of ESRI's CityEngine software, which is now used by urban planners and digital twin developers worldwide to generate city-scale 3D models from cadastral and geospatial data.

The pipeline that 51World uses in its Earth Clone platform to convert aerial imagery, LiDAR point clouds, and cadastral data into photorealistic 3D city models at city scale (Najafi, 2025) is not simply an adaptation of game-derived PCG techniques, it is the direct descendant of the same shape grammar lineage that game developers and computer graphics researchers developed together over two decades of research. What has changed substantially in recent years is the role of machine learning in automating and enriching this pipeline. Airborne LiDAR has become particularly important among sensing technologies for urban modelling, with its ability to accurately capture large-scale geometry proving especially promising for city-scale perception of urban environments, and deep learning are now being trained to convert raw point cloud data directly into watertight polygonal mesh models of individual buildings, automating a reconstruction step that previously required intensive manual processing. These machine learning driven reconstruction pipelines represent the frontier of procedural city modelling for digital twins: they do not replace the rule-based grammar systems, but augment them, using learned models to handle the irregular, incomplete, and geometrically diverse input data that real airborne surveys produce, while grammar-based systems continue to govern the synthesis of street networks, urban blocks, and architectural detail at scales and speeds that data-driven reconstruction alone cannot yet match (Karaca et al., 2023).

4.5 Multiplayer Networking and Collaborative Urban Governance

Online multiplayer games require robust, low-latency networking architectures that synchronise a shared virtual world across thousands of simultaneous users. This technical challenge is isomorphic to the challenge facing collaborative Urban OS platforms, which must synchronise the state of a city's digital twin across dozens of municipal departments, thousands of data acquisition IoT sensors, and potentially millions of citizen-facing applications simultaneously. The emerging CitiVerse concept by the International Telecommunication Union (ITU)'s (2025) Global Digital CitiVerse Framework essentially describes a massively multiplayer experience of the city, in which citizens, planners, and administrators interact with a shared digital representation of their urban environment.

5 Urban Digital Twins as Serious Game Worlds

The technology transfer described above is not theoretical, it is demonstrably instantiated in the most advanced urban digital twin implementations currently in operation.

5.1 Shanghai Case Study

Shanghai's city-scale digital twin, developed by 51World on the Unreal Engine-powered 51AES Earth Clone platform, represents one of the most ambitious deployments of game engine technology in urban governance currently documented (Najafi, 2025). The project's technical achievement, photorealistic, interactive representation of 3,750 km^2 integrating data from 20 municipal agencies, is inseparable from the gaming industry's prior investment in real-time rendering, LOD management, and physics simulation (Weir-McCall, 2020).

Figure 8. Aerial perspective of Shanghai's digital twin showing the Lujiazui financial district with photorealistic rendering of skyscrapers, transportation infrastructure, and the Huangpu River. The visualisation demonstrates real-time lighting and atmospheric effects achieved through Unreal Engine rendering; capabilities directly derived from game engine development. Image courtesy of 51World, used with permission (Najafi, 2025).

As documented by Najafi (2025, 2026), the Shanghai Urban OS performs a range of functions drawing directly on game engine capabilities. Real-time flood modelling integrates rainfall data, terrain models, and drainage sensor feeds using physics simulation systems to predict inundation zones, an application of fluid simulation technology similar in its computational approach from water physics that make ocean surfaces believable in modern games. Dynamic traffic signal optimisation relies on agent-based AI models that are the functional equivalents of traffic NPC systems in open-world games.

The flood simulation capabilities of Shanghai's digital twin (Figure 9) provide a clear illustration of the game-to-city technology pathway. The 51WIM platform simulates river and lake hydrodynamics by integrating real-time rainfall data, terrain models, and sensor feeds in a physics engine that calculates water flow direction, velocity, and inundation extent in real time. The visual representation, particle systems, streamlines, animated water surfaces, is visually indistinguishable from a game water simulation. Yet its output, forecasts of flood zones, optimal evacuation routes, infrastructure vulnerability maps, is used by city officials to make life-or-death decisions during typhoon events.

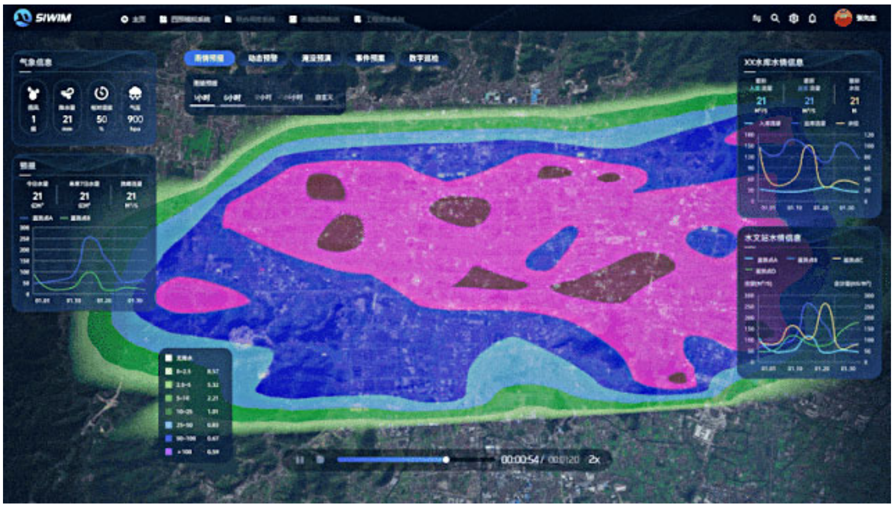

Figure 9. 51World's 51WIM Digital Twin Water Conservancy Platform simulating river and lake direction and velocity to predict flooding events. The fluid dynamics underlying this simulation system shares its computational lineage with water physics in modern game engines. Image courtesy of 51World, used with permission.

5.2 Singapore Case Study

Singapore's Virtual Singapore national digital twin represents a different but equally illuminating application of game engine technology. Singapore's approach emphasises extraordinary precision, incorporating LOD 3 and LOD 4 models including not just building exteriors but interior spaces, structural components, and subterranean infrastructure. This multi-resolution modelling approach, where different parts of the city are represented at different levels of geometric detail based on governance importance, is the direct application of LOD techniques that game engines pioneered to balance visual quality against computational performance (Figure 10).

Figure 10. Real-time road traffic visualisation in Singapore's digital twin, demonstrating the integration of live sensor data with game engine rendering (LOD 1 and 2 in this figure). Traffic flow patterns rendered in this way mirror the AI-driven vehicle behaviour systems used in open-world driving games. Image courtesy of 51World, used with permission.

5.3 Riyadh Case Study

Riyadh's evolving urban digital twin illustrates how game rendering capabilities are enabling urban governance in contexts where physical infrastructure and digital infrastructure are being constructed simultaneously. The platform, created in Unreal Engine by 51World, serves as a common cloud-based data environment where international planning teams, architects, and city officials collaborate on the city's rapid expansion, a use case structured like a collaborative 3D game design tool, where multiple contributors work in a shared virtual environment (Figure 11).

Figure 11. Riyadh's high-detail digital twin created in Unreal Engine, illustrating the photorealistic rendering quality achievable through game engine technology for urban governance. The visual fidelity, comparable to modern open-world games, serves critical stakeholder communication and planning validation functions. Image courtesy of 51World, used with permission.

6 Smart Cities Informing Gaming

The technology transfer documented above flows primarily from gaming to urban governance, but it is not unidirectional. The demands of urban digital twins are creating a reverse current enriching the gaming sector in important ways.

The most immediate reverse flow is in data and geographic fidelity. The development of urban digital twins has accelerated investment in geospatial data capture, such as high-resolution satellite imagery, LiDAR point cloud libraries and photogrammetric terrain models that all are directly usable by game developers to create authentically realistic virtual cities. The procedural city generation pipelines co-developed for digital twins are already being adapted by game studios to create more convincingly realistic open-world environments.

More conceptually significant is the CitiVerse vision articulated by the ITU (2025), which explicitly frames the evolution of urban digital twins toward increasingly immersive, participatory, and gamified interfaces as a convergence of physical urbanism and digital world-building. This vision encompasses citizen-facing applications where residents navigate photorealistic representations of their cities, contribute crowdsourced data, and experience proposed urban changes as if they were real.

The growing discipline of urban gamification, using game mechanics such as challenge, reward, progress, and narrative to engage citizens in sustainability behaviours and civic participation, also draws directly on game designer expertise (Jolly & Budke, 2023). Cities including Helsinki and Adelaide have experimented with game-based urban planning consultations, and academic researchers are increasingly investigating how engagement techniques honed by game designers can make democratic urban governance more effective (Ene et al., 2026). There is also a philosophical reverse flow. The journalist Layla Poon's observation that digital twin cities are *SimCity for policymakers* captures this transfer (Poon, 2022). The game genre provided the conceptual model, a navigable, responsive, consequence-revealing urban simulation that has now been realised at real-world scale and genuine policy relevance.

7 The Game-City Continuum

This paper suggests the need for a conceptual framework capturing the relationship between game design and urban digital twins not as historical accident but as a structural feature of the contemporary technology landscape. This paper proposes the *Game-City Continuum* as such a framework.

The Game-City Continuum identifies a spectrum along which virtual environments and real urban systems are increasingly convergent, mapped across three dimensions: fidelity (the degree to which the virtual environment accurately represents its physical counterpart), agency (the degree to which users can modify the environment and observe consequences), and connectivity (the degree to which the virtual environment is linked to real-time data from the physical world). At one extreme sit traditional SimCity like city-building games: high agency, variable fidelity, zero connectivity. At the other extreme sit the most advanced Urban OS implementations: maximum connectivity, increasing fidelity, and growing agency through citizen-facing interfaces, similar to 51 Worlds platforms. In between lies a rich landscape of intermediate applications: serious games for urban planning education, participatory digital twin consultations, gamified smart city citizen apps, and collaborative game-engine-based design tools.

This framework has important implications. First, the technology roadmaps of game engine developers (Epic Games, Unity, NVIDIA) and urban digital twin platform developers (51World) will continue to converge, and cross-sector partnerships will become increasingly important. The World Economic Forum's (2022) 4+5 Digital Twin Cities framework and the ITU's (2025) CitiVerse framework both implicitly acknowledge this convergence. Also, urban planners and policymakers need to understand the game industry as a source of expertise and innovation, not merely a consumer technology sector. There is also a critical research gap: the underexplored question of how the epistemological biases embedded in game design and game language, its tendency toward top-down control, its simplified economic models, its optimisation of legible feedback loops at the expense of social complexity, may be encoding themselves into urban governance frameworks when game-derived technologies are adopted without critical reflection.

SimCity's origins in Forrester's *Urban Dynamics* encoded a particular, contestable vision of cities as mechanically controllable systems whose problems could be resolved by optimal resource allocation (Simon, 2020). Critics argue this vision subtly shaped the assumptions of smart city discourse and its confidence in data-driven optimisation, its tendency to see governance as a technical rather than political challenge, its relative inattention to the social dynamics of race, class, and power that shape real urban outcomes (Szot, 2024). As game engine technology becomes foundational to urban governance platforms, urban practitioners have a responsibility to interrogate what design philosophies these platforms are importing alongside their rendering capabilities.

8 Governance, Ethics, and the Challenges of Convergence

The convergence documented in this paper creates not only opportunities but challenges that must be addressed by both the gaming industry and the urban governance community.

The first is algorithmic transparency. As Najafi (2026) mentions, city digital twin platforms increasingly move from descriptive mapping to prescriptive governance, actively recommending urban interventions based on AI model outputs. Some of these AI systems underpinning these recommendations have their technical lineage in gaming AI, designed primarily for entertainment value rather than civic accountability. Translating these systems into governance contexts requires embedding explainability, auditability, and human-in-the-loop oversight (Haraguchi et al., 2024). The risk of what scholars call *digital tyranny* (urban governance by opaque algorithms) must be countered by frameworks mandating transparency and accountability.

The second challenge is equity and access. The photorealistic, immersive interfaces that game engines enable are cognitively and technically accessible primarily to users with digital literacy and modern hardware. If citizen-facing urban digital twin interfaces are designed with the expectations of gamers rather than the full diversity of a city's population, they risk creating a two-tier information environment (Zhu & Jin, 2025).

The third challenge is the energy cost of photorealism. The computational intensity of game engine-based urban visualisation consumes significant energy. As Najafi (2026) notes, the energy footprint of large-scale digital twin computation is an emerging concern, and the pursuit of photorealism, driven partly by gaming industry aesthetic standards, may not always be justified by governance value.

The fourth challenge, convergence raises questions about data governance and sovereignty. The rich behavioural and spatial data generated by urban digital twins is exactly the kind of data that gaming companies have long coveted for personalisation and monetisation. As urban and gaming platforms converge technologically, the boundary between civic data infrastructure and commercial data extraction must be actively maintained through robust governance frameworks, including the data sovereignty and digital self-determination principles advocated by Verhulst (2023). The Gemini Principles (Bolton et al., 2018), the UK National Digital Twin programme (Kendall, 2021), and Barcelona's data commons approach (Bria, 2019) all provide relevant models to address this data governance and sovereignty issue.

9 Conclusion

This paper has argued that the convergence between the game design and entertainment industry and the smart city digital twin sector is a convergence that is simultaneously more specific and more consequential than is generally appreciated. It is not merely a matter of visual aesthetics, but a deep structural integration of rendering pipelines, physics simulation engines, AI agent systems, procedural generation techniques, and networked collaboration architectures that were developed for entertainment and have now become foundational to real-time urban governance.

The evidence cases examined in this paper, from Shanghai's photorealistic city-scale twin running on Unreal Engine to Singapore's precision national model, from Riyadh's rapidly constructed cognitive city platform to the emerging CitiVerse frameworks, confirms that this transfer is already operational at the highest levels of urban governance globally. The technology roadmaps of Epic Games, NVIDIA, and 51World are explicitly oriented toward deepening this convergence, and market projections suggest that investment flows sustaining it will only accelerate.

The Game-City Continuum framework proposed in this paper provides a conceptual vocabulary for understanding this relationship as a structural feature of the contemporary technology landscape. It maps the spectrum from pure entertainment to pure urban governance across dimensions of fidelity, agency, and connectivity, identifying the critical transition zone where design choices made in one domain have direct consequences in the other.

The cities of the future will be, in a very real sense, serious games, in other words, virtual environments of extraordinary fidelity and connectivity that allow their citizens and governors to explore, test, and shape the urban world before acting in it. The question is not whether the game design industry will contribute to building these cities, but whether the transfer of its technologies will be accompanied by the critical reflection and fair governance that the stakes demand.

Ethical Approval Declaration

Not Applicable

Informed Consent Statement

Not Applicable

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Conflicts of Interest

The authors declare no conflict of interest.

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