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A Gaia-Inspired Framework for Geogames: Bridging Theory and Practice to Design and Assess Games

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Abstract

The field of geogames, positioned at the intersection of serious games and geographic information systems (GIS), remains theoretically fragmented and underexplored. This article addresses that gap by introducing a novel framework that integrates game studies with the Gaia hypothesis, as proposed by Lovelock and Margulis and expanded through post-humanist perspectives. While game studies provide valuable insights into mechanics, narratives, and player engagement, they often overlook the spatial, ecological, and systemic dimensions essential to geogames. Gaia theory, which conceptualizes Earth as a self-regulating system of interdependent components, offers a systems-thinking approach that aligns with the ecological and urban complexities modeled in geogames. This article critiques the anthropocentric bias in current geogame design, advocating for an ecocentric paradigm. To this end, based on the theoretical foundation, we propose four lenses of geogames (Gaia + Games): feedback mechanisms, co-evolutionary dynamics, multispecies interactions, and planetary thresholds. These four lenses are then further explained and operationalized into a Gaia Design Framework—a toolbox for both geogame design and assessment. By synthesizing Gaia's principles with urban and architectural analysis, our framework illustrates how geogames can serve as powerful tools to foster collaborative design, model human and non-human complexities, and explore regenerative solutions to pressing urban and planetary challenges. Our study challenges scholars and practitioners to rethink the role of games in shaping sustainable futures, positioning geogames as critical methods and tools for addressing the intertwined crises of urbanization and ecological and climate degradation.

Keywords

Gaia theory; game assessment; game design; geogames; urban regeneration

1. Introduction

Geogames—operating at the nexus of serious games and geographic information systems (GIS)—are defined as digital and analog games that embed real-world geospatial data and dynamics to model complex environments, serving as vital instruments for urban planning, ecological modeling, and participatory governance (Ahlqvist & Schlieder, 2018; Poplin et al., 2020). More than mere playful simulations, they function as volatile hybrids of simulation model, participatory platform, and speculative design instrument that render urban complexity playable, where every rule, resource counter, or growth threshold inscribes a politics of futurity and a reflection of urban power dynamics. In the context of urban planning, they are recognized for their potential to facilitate co-creation, learning processes, and collaborative exploration of contested futures in a way that traditional methods often fail to capture. Yet, as cities grapple with climate breakdown, biodiversity collapse, and infrastructural precarity, the limitations of conventional serious games and geogames design become starkly apparent.

Too often, these games reproduce the very anthropocentric logic that has precipitated planetary crisis: They treat space as an inert canvas for human intervention rather than a contested, dynamic, and more-than-human system (Haraway, 2016; Latour, 2017). The result is a paradox: games capable of simulating urban complexity, yet incapable of confronting the political-ecological entanglements that define the Anthropocene, such as climate-driven displacement, fossil-fuel lock-ins embedded in urban infrastructures, biodiversity collapse linked to land-use change, and the unequal distribution of environmental risks across marginalized communities.

This article argues that the Gaia concept, when critically reframed beyond Lovelock and Margulis' original hypothesis, offers a radical lens for reimagining geogames. While Lovelock and Margulis (1974) pioneered the idea of Earth as a self-regulating system, their framework risks depoliticizing ecological relations, reducing planetary dynamics to a closed feedback loop devoid of human agency, conflict, or power asymmetries (Doolittle, 2019). Such a view is insufficient for geogames, which must engage with the messy realities of urban climate adaptation, multispecies coexistence, and contested futures. Instead, we turn to post-humanist reinterpretations of Gaia—Latour's (2017) warrior Gaia, Stengers' (2015) unpredictable intruder, and Haraway's (2016) "sympoietic collaborator"—to confront the omissions in current geogame theory and practice.

Latour's (2017) Gaia is no harmonious superorganism but a politicized force that resists human mastery, exposing the futility of solutions that ignore power relations (e.g., climate policies that exacerbate inequality). Stengers (2015), in contrast, warns against instrumentalizing Gaia altogether, framing it as a process of becoming that defies human control, a necessary corrective to gamified fixes for wicked problems. Haraway (2016), meanwhile, reorients Gaia as a practice of sympoiesis (making-with), emphasizing the embodied, uneven collaborations between species, technologies, and infrastructures. Together, these perspectives demand a geogame paradigm shift that does not merely simulate ecosystems but stages their contested realities: where zoning decisions provoke ecological backlash, where non-human actors disrupt human plans, and where winning requires negotiating with, rather than dominating, planetary systems.

Our project is both theoretical and pragmatic, offering a critical examination of the anthropocentric assumptions embedded in serious games and geogames scholarship. These include the neglect of

political-ecological feedback and the erasure of more-than-human agency. To address these gaps, we propose a Gaia Design Framework that redefines geogames as critical media for Gaia politics, integrating three interconnected dimensions from post-humanist perspectives. First, antagonistic feedback draws on Latour's (2017) concept of political Gaia, modeling dynamic systems where urban interventions provoke ecological counter-actions—such as flood defenses failing due to policy loopholes or carbon trading schemes destabilizing ecosystems—underscoring the futility of unilateral human control. Second, unpredictable emergence reflects Stengers' (2015) notion of Gaia intrusions, incorporating non-linear systems that defy player mastery, such as urban heat islands disrupting energy grids or pollinator collapses unraveling food systems, revealing the unpredictable logics of ecological systems that challenge anthropocentric planning. Finally, sympoietic design actualizes Haraway's (2016) making-with philosophy through interdependent gameplay systems, where players collaborate with pollinator colonies or adapt infrastructure to tidal patterns, illustrating that sustainable urban futures depend on mutual adaptation between human and more-than-human actors rather than human dominance. Together, these dimensions position geogames as vital tools for rethinking the relationship between urbanization and ecological resilience.

This is not a call for escapist fiction but for speculative rigor, games that encourage players to confront the consequences of their decisions beyond human-centric metrics. We propose a framework where success hinges on satisfying both corporate developers and lichen colonies, or where algorithmic climate models rebel against simplistic policy inputs. Such games would not just teach systems thinking; they would render planetary tensions sensorially and politically palpable, impossible to ignore any longer. The stakes extend beyond academia. If urban and regional planning is to navigate the Anthropocene's turbulence, it needs tools that reject the illusion of human sovereignty. Geogames, reworked through a critical Gaia lens, could be those tools, not because they offer answers, but because they refuse simplistic ones. This article charts a path forward, one where play becomes a mode of thinking-with the planet's unruly, politicized, and collaborative futures.

2. Theoretical Foundation

Geogames inhabit an uneasy territory between serious gaming and geospatial technology—neither emancipatory planning panacea nor trivial digital toy, but volatile hybrids that render urban complexity playable (Ahlqvist & Schlieder, 2018). Every zoning rule, resource counter, or growth threshold inscribes a politics of futurity, transforming Batty's (2007) nonlinear urban models into procedural form. Early analog experiments such as Design Games (Sanoff, 1979) and Metropolis (Duke, 1974) promised participatory insight yet often concealed power asymmetries beneath consensus rhetoric, a critique that resurfaces in contemporary board-game revivals (Sousa, 2024). The digital turn only deepened these contradictions: Play the City (Tan, 2017) showed how role-play can expose conflict more vividly than algorithmic dashboards, while analyses of Block by Block and classroom Minecraft designs (Andrade et al., 2024) reveal how inclusive platforms frequently privilege the digitally fluent and institutionally endorsed. As Mayer et al. (2005) warned, the ruleset itself is the battleground where fairness is coded or denied.

Two dominant lineages now shape the geogames genre. The first is the sanitised SimCity clone, reducing urbanism to supply-chain optimisation and population growth (Juul, 2005); the second is the co-optative serious game that gamifies austerity planning in the language of participation (Poplin et al., 2017). Yet critical counter-currents exist. These outliers fundamentally challenge the anthropocentric assumptions of the

dominant lineages by procedurally embedding ecological complexity and non-human agency into their core mechanics. RElastiCity: An Urban Resilience Game (TU Delft Gamelab, 2021) challenges players to maintain urban resilience by managing resources and responding to ecological shocks, a stance that prioritizes long-term stability over short-term optimization; Block'hood (Plethora Project, 2017) visualises metabolic feedback loops; Eco (Strange Loop Games, 2018) encodes escalating climate regulation into server law; and Planet Zoo (Frontier, 2019) centres non-human welfare as a scoring metric, directly subverting the conventional prioritization of human progress metrics. Hybrid projects such as Sousa's (2024) stakeholders' clash game for urban planning or the Cosmopolitical Board Game for cultural heritage (Andrade et al., 2024) demonstrate how analog mechanics can destabilise digital determinism. Such a shift requires moving beyond both analog nostalgia and digital fetishism to embrace critical play (Flanagan, 2009) that weaponizes game systems against contemporary urban and planetary issues. These outliers prefigure the Gaia lenses elaborated in our methodology, yet most existing titles still sidestep the ecological politics they visualise.

The canon of game studies remains trapped in a "human-exceptionalist" paradigm (Haraway, 2016), brilliantly deconstructing play's formal structures (Aarseth, 1997; Juul, 2005) while remaining blind to spatial and ecological agency. This theoretical lacuna manifests in three fatal assumptions that constrain geogame potential. First, the player-centric fallacy reduces environments to narrative backdrops rather than active systems (Frasca, 2003), mirroring the Cartesian divide that enables ecological crisis. For example, Adams' (2014) framing of game worlds as "containers for gameplay" replicates what Latour (2017) critiques as the modernist illusion of passive space awaiting human design. In contrast, Brković Dodig and Chiles' (2016) Spector game engages pupils in co-creating sustainability knowledge within their schools, prioritizing experiential, context-based education while leaving room for future iterations. Second, procedural reductionism reflects the field's obsession with universal mechanics (Juul, 2005), ignoring what Haraway (2016) calls "situated knowledge."

Urban systems rarely follow neat, rule-based patterns; instead, they unfold in complex, place-specific ways. Tan's (2017) analog role-playing games capture this urban messiness, while digital designs often flatten such complexity into rigid frameworks. The Cosmopolitical Board Game (Andrade et al., 2024) offers a compelling alternative by positioning sacred trees as active political agents, requiring players to negotiate with waterways and green spaces as stakeholders in the city of Salvador, Brazil. Yet, victory condition myopia distorts urban complexity by reducing it to win/lose binaries (Juul, 2005). As Fernández Galeote and Hamari (2021) observe, while gamification and game-based learning can enhance engagement with climate change, they also risk simplifying or obscuring the slow, cumulative impacts that characterize phenomena like Nixon's (2011) "slow violence." This helps explain why most urban planning games reward growth over resilience (Poplin et al., 2020), whereas Andrade and Pereira Roders' (2022) heritage games challenge players to address heritage vacancy crises by exploring nature-based solutions that integrate ecological strategies into revitalizing abandoned buildings and sites.

Even the foundational debate in game studies—ludology's rules versus narratology's stories (Aarseth, 1997; Frasca, 2003)—fails to engage ecological thought. Both sides assume a human protagonist: Whether players conquer systems (ludology) or interpret meanings (narratology), the environment remains a stage. The consequences of anthropocentrism are palpable. Games often misrepresent feedback loops (e.g., portraying pollution as a debuff rather than a cascading threshold breach), erase more-than-human stakeholders (e.g., zoning games where soil health has no procedural representation), and prioritize speed

over deliberation (e.g., real-time strategy mechanics applied to decades-long urban transitions). Addressing these flaws requires dismantling foundational assumptions. Frasca's (2003) simulation theories could integrate Latour's (2017) actor-networks, and Aarseth's (1997) cybertext framework could embrace Haraway's (2016) sympoiesis. The tools exist, but the geogames field lacks the cosmovision to use them, or a worldview that includes non-Western, non-anthropocentric conceptions of human–nature relationships.

The original Gaia hypothesis (Lovelock & Margulis, 1974) conceptualized Earth as a self-regulating superorganism, but its vision of planetary homeostasis feels dangerously anachronistic in the age of climate breakdown. Its greatest flaw lies in its inability to account for the Capitalocene—a term used to describe the violent entanglement of human industry, colonial extraction, and ecological rupture driven by capitalism—which is a more precise term for referring to power asymmetries than the Anthropocene. Lovelock and Margulis' Gaia lacks a vocabulary for the power asymmetries that determine whose cities get seawalls and whose communities drown. Post-humanist reworkings of Gaia by Latour, Stengers, and Haraway confront these political, unpredictable, and collaborative dimensions of planetary life, offering the conceptual notions needed to revolutionize geogames. Latour (2017) reframes Gaia, conceptualizing the planet as a battlefield where climate change is not a system malfunction but Gaia's general strike. For geogames, this means designing mechanics that model conflict and resistance, such as zoning policies that trigger algorithmic revolts from urban forests or infrastructure projects that mobilize digital floods to reclaim watersheds. Conversely, Stengers (2015) warns against reducing Gaia to an adversary, emphasizing its radical unpredictability. This demands game mechanics that actively undermine player control, where rising seas mutate in response to player actions and solutions generate unintended consequences. Haraway's (2016) concept of sympoiesis offers a third path, envisioning Gaia as a collaborative process of multispecies world-making. Geogames inspired by this approach demand a design methodology that actively integrates the interests and agency of more-than-human beings into the core game flow, mechanics, and design logic, thereby emphasizing co-creation over unilateral human control.

Together, these thinkers provide a new paradigm for geogame design: urban spaces as negotiation arenas with agentic ecologies, game systems embracing radical uncertainty, and play as an exercise in co-creation. This paradigm is no mere theoretical exercise. These conceptual shifts anchor the Gaia Design Framework developed in the Methodology section and deployed in the Results. By coupling feedback mechanisms, co-evolutionary dynamics, multispecies interactions, and planetary thresholds to specific visual, narrative, procedural, temporal, and incentive levers, the framework translates theory into design practice. In doing so, it positions geogames as Latourian diplomatic assemblies where floodwaters, mushrooms, and disenfranchised residents negotiate sustainable urban futures, not abstractly, but through the very rules that constitute play.

3. Methodology

The methodology for this study is grounded in a critical examination of contemporary geogames, which often perpetuate anthropocentric paradigms and fail to address the complexities of urban–ecological systems. Drawing on Gaia theory and post-humanist thought, this research proposes a transformative framework for both geogame design and assessment, structured around four Gaia-inspired lenses: feedback mechanisms, co-evolutionary dynamics, multispecies interactions, and planetary thresholds. These lenses, derived from the theoretical framework, aim to dismantle the "modernist divide" (Latour, 2017) between society and nature, embedding ecological complexity and more-than-human agency into game systems.

3.1. Gaia Lenses for Geogame Design

Our Gaia Design Framework offers a provocative and transformative framework for reimagining geogames as tools for navigating the intertwined crises of urban degradation and ecological collapse. Rooted in Gaia theory, the framework challenges the anthropocentric logic that has long dominated game design. It shifts the focus from human-centered simulations to systems of more-than-human negotiation, where the agency of non-human actors—trees, cats, ancestors—becomes central to gameplay. This approach not only reflects the complexity of planetary systems but also compels players to confront the ethical and cosmopolitical dimensions of living within ecological limits, resisting the fatalism of the coming barbarism Stengers (2015) warns against.

At its core, the framework integrates four lenses—feedback mechanisms, co-evolutionary dynamics, multispecies interactions, and planetary thresholds—into a unified framework, each addressing critical aspects of planetary systems. Feedback mechanisms focus on systemic interconnections, using tools like heat maps, delayed smog effects, and air-quality recovery to visualize cascading impacts. Co-evolutionary dynamics explore the interplay between human and ecological systems, with mechanics like construction freezes and flash-forwards simulating long-term consequences. Multispecies interactions foreground non-human agency, featuring elements like bee corridors, tree agents, and rivers narrating their histories to challenge anthropocentric perspectives. Finally, planetary thresholds emphasize the fragility of Earth's systems, with mechanics such as CO_2 limits, shoreline loss, and flood-damaged land recovery highlighting the stakes of crossing critical boundaries. Together, these lenses transform geogames into tools for critical reflection and systemic thinking, fostering a deeper understanding of ecological interdependence.

The framework's critical potential lies in its ability to provoke reflection and resistance. By embedding Gaia principles into game architectures, it challenges players to rethink their relationship with the Earth, moving beyond the extractive logic of the Anthropocene. Yet, as Stengers reminds us, the intrusion of Gaia is not a call for despair but an invitation to imagine alternative futures rooted in care, humility, and collective action. The framework embodies this ethos, transforming geogames into spaces of critical experimentation where players can explore the ethical dilemmas and systemic consequences of their decisions. It resists the illusion of control, instead fostering a sense of accountability that transcends individual lifetimes and geographic boundaries.

Our Gaia Design Framework (Figure 1) was developed through a systematic, two-step iterative process: literature triangulation and framework synthesis. First, we cross-mapped four core Earth-system processes—nonlinear feedbacks, co-evolutionary dynamics, multispecies interactions, and planetary thresholds—with the socio-ecological questions central to contemporary urban research (Batty, 2013; Beatley, 2012; Rockström et al., 2009). Simultaneously, insights from game studies (Aarseth, 1997; Flanagan, 2009) clarified which ecological dynamics are often overlooked in city-building simulations. This process yielded a shortlist of "design-critical" concepts that a Gaia-aligned geogame should address, transforming abstract theory into procedural concerns. The selection of these four lenses is not arbitrary. They integrate the core post-humanist perspectives of Gaia (Latour's antagonism, Stengers' unpredictability, Haraway's sympoiesis) with the necessity of modeling Earth-system limits. They collectively address the fatal anthropocentric assumptions in current geogame design, ensuring that complexity, agency distribution, and irreversibility are integrated into the core game mechanics.

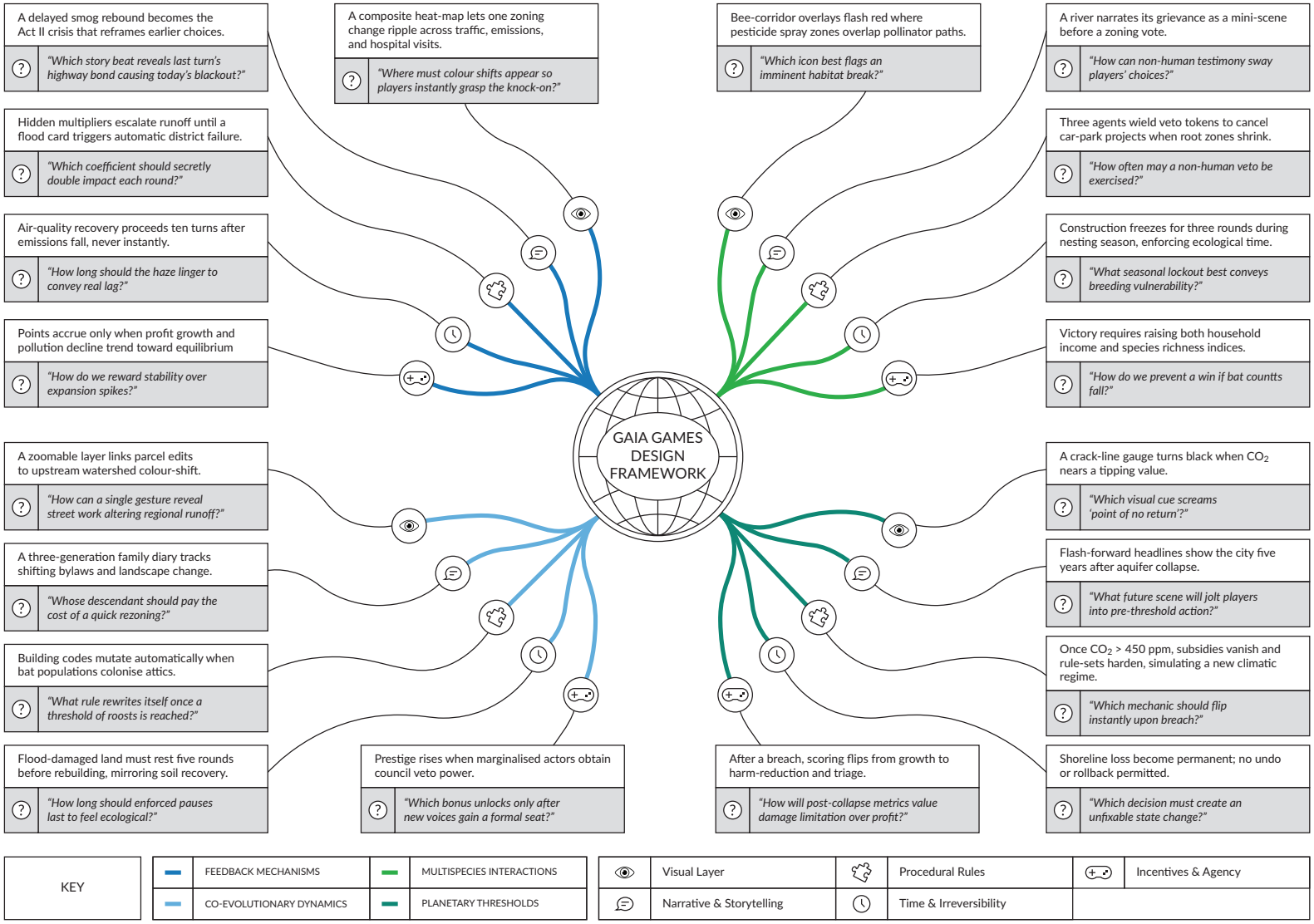

Figure 1. Four-lenses conceptual framework for geogames (Gaia + Games) design.

3.1.1. Feedback Mechanisms: Nonlinear Urban--Ecological Loops

Feedback mechanisms emphasize the interconnectedness of urban and ecological systems, focusing on nonlinear dynamics, delays, and cascading effects. This lens challenges the linear cause–effect logic of traditional geogames, instead modeling complex loops where small actions can trigger disproportionate consequences. Drawing on Batty's (2007) exploration of complexity in urban systems and Lovelock's (2000, 2006) Gaia theory, feedback mechanisms highlight the dynamic interplay between amplifiers (positive feedback) and dampers (negative feedback) in regulating urban–ecological systems. Batty's work on cellular automata, agent-based models, and fractals underscores how small, localized changes can propagate through systems, creating emergent patterns and unexpected outcomes.

For example, urban sprawl may initially improve housing availability but later destabilize ecosystems through deforestation and water table depletion. Similarly, algal blooms in water bodies can amplify global warming by releasing methane, while urban green spaces can dampen heat island effects, demonstrating the dual nature of feedback loops. Geogames mechanics could incorporate delayed smog effects, where pollution accumulates invisibly before triggering health crises, or composite heat maps that visualize cascading urban heat impacts. Hidden multipliers, such as methane release from wetlands or the compounding effects of deforestation, could challenge players to anticipate long-term consequences rather than focusing on immediate rewards. Additionally, zoomable layers could allow players to explore feedback loops at different scales, from local neighborhoods to regional ecosystems.

To effectively address feedback mechanisms and guide geogame design projects, the following questions can serve as critical triggers: How can delayed feedback loops, such as groundwater depletion or air-quality recovery, be visualized to make invisible processes tangible to players? What dynamics emerge when players are rewarded for short-term gains but penalized for long-term ecological overshoot, and how can this tension be embedded into gameplay mechanics? How might hidden multipliers, like methane release from wetlands or cascading effects of shoreline loss, challenge players to rethink resource management and urban and regional planning strategies? Finally, how can visual storytelling—such as a river narrating its pollution history—help players grasp the systemic and far-reaching consequences of their actions?

3.1.2. Co-Evolutionary Dynamics: Mutual Transformation Across Scales

Co-evolutionary dynamics explore the reciprocal and iterative relationship between built environments and biophysical systems, emphasizing how they reshape one another over time and across spatial scales. This lens draws on Margulis' (1998) work on symbiosis, which highlights mutualistic relationships as drivers of evolutionary processes, and Latour's (2017) actor-network theory, which emphasizes the entanglement of human and non-human agents in shaping socio-ecological systems. For example, light pollution disrupts nocturnal animal behavior, which in turn alters vegetation patterns and urban biodiversity, demonstrating the cascading effects of human interventions. Similarly, urban heat islands influence local weather patterns, which feed back into urban planning decisions, creating a dynamic co-evolutionary loop. Batty's (2007) exploration of complexity in urban systems further underscores how small, localized actions—such as zoning changes or tree planting—can ripple outward, producing emergent patterns that reshape entire communities.

Geogames mechanics can operationalize co-evolutionary dynamics by simulating the mutual transformation of urban and ecological systems. For instance, tree agents could influence urban planning decisions by

altering soil stability, shading, or air quality, evolving over time to reflect the long-term impacts of urban development. Seasonal migrations or ecological thresholds could trigger construction freezes, forcing players to adapt their strategies to accommodate non-human needs. Flash-forward mechanics could reveal the long-term consequences of short-term urban policies, such as the impact of unchecked urban sprawl on regional ecosystems. Additionally, dynamic governance systems could evolve in response to ecological changes, such as floodplain zoning regulations adapting after a major storm, challenging players to think beyond immediate outcomes and consider broader, long-term implications.

To guide the design of geogames that incorporate co-evolutionary dynamics, several critical questions arise: How can governance systems in games evolve dynamically in response to ecological changes, such as floodplain zoning after a major storm or the introduction of invasive species? What happens when players must negotiate with non-human agents, such as bee colonies or migrating birds, to unlock urban development options? How can flash-forward mechanics be used to reveal the long-term consequences of short-term urban policies, such as the effects of deforestation or wetland destruction on regional ecosystems? Finally, how might visual storytelling—such as a tree narrating its growth and decline in response to urbanization—help players grasp the systemic and far-reaching consequences of their actions?

3.1.3. Multispecies Interactions: More-Than-Human Agency in Urban Systems

Multispecies interactions foreground the agency and stakes of non-human actors in urban systems, reimagining them as active participants rather than passive resources. This lens challenges anthropocentric paradigms by embedding non-human entities—such as rivers, pollinators, and mushrooms—into decision-making processes, drawing on Haraway's (2016) concept of sympoiesis, which emphasizes collaborative and interdependent systems. Tsing (2015) further highlights the entangled survival strategies of human and non-human actors in precarious environments, while Despret (2016) explores the relational and performative dimensions of non-human agency. These works underscore the need to rethink urban systems as multispecies assemblages, where rivers narrate their histories of pollution, bee corridors shape agricultural zones, and mushroom communities influence soil health. Such interactions reveal the profound interdependence between human and non-human beings, compelling players to confront the ethical implications of their decisions.

Geogames can operationalize multispecies interactions by introducing mechanics that give non-human agents tangible roles in gameplay. For instance, tree agents could influence urban planning by altering soil stability or air quality, evolving over time to reflect the long-term impacts of urbanization. Bee corridors could serve as critical pathways for pollination, requiring players to maintain biodiversity to ensure agricultural productivity. Visual storytelling could further enhance these interactions, with rivers narrating their pollution histories or mushrooms responding dynamically to player actions. These mechanics shift the focus from human control to multispecies negotiation, encouraging players to consider the needs, agency, and resilience of non-human actors in urban systems. By doing so, geogames can challenge players to think critically about the shared futures of human and non-human communities.

To guide the design of geogames that incorporate multispecies interactions, several critical questions arise: How can non-human testimony, such as a river narrating its pollution history, be integrated into gameplay to make ecological processes more tangible? What ethical dilemmas emerge when players must prioritize the

needs of non-human agents over human development goals? How can multispecies victory conditions, such as biodiversity thresholds or pollination success rates, redefine success in geogames? Finally, how might visual and procedural storytelling help players grasp the systemic and far-reaching consequences of their actions on more-than-human systems?

3.1.4. Planetary Thresholds: A Critical Framework for Sustainability

Planetary thresholds represent the critical boundaries within Earth's systems that, if crossed, could lead to irreversible ecological collapse. Rockström et al. (2009) conceptualized these thresholds as limits to processes like climate regulation, biodiversity loss, and biogeochemical cycles, which collectively maintain the planet's stability. We acknowledge that the concept of planetary boundaries has faced significant critique, particularly concerning the risk of its instrumentalization, which can obscure the profound social and political inequalities that underpin ecological crises. However, Stengers (2015) argues that these thresholds are not neutral scientific markers but sites of profound ethical and political struggle. The author critiques the framing of Gaia as a vengeful force, warning against narratives that reduce ecological collapse to an inevitable punishment for human hubris. Instead, she calls for a radical rethinking of our relationship with Gaia—not as a deity to appease but as a force that demands humility, care, and resistance to the fatalism of modernity. This perspective challenges the illusion of control over planetary systems, urging us to confront the systemic violence and inequalities that underpin urban–ecological crises.

Planetary thresholds are operationalized as dynamic constraints that shape gameplay and decision-making. Mechanics like "Once $CO_2 > 450$ ppm" or "Flood-damaged land must rest" simulate the cascading effects of crossing critical boundaries, forcing players to grapple with the fragility of Earth's systems. Still, as Stengers (2015) reminds us, these mechanics must go beyond mere simulations of control to provoke critical reflection on the limits of human agency. Geogames mechanics must emphasize systemic thinking—where every action reverberates across ecological networks—as a call to resist the reduction of Gaia to a manageable system. By embedding planetary thresholds into gameplay, players are compelled to confront the irreversible tipping points and systemic risks, where the consequences of inaction or mismanagement are not abstract but visceral and immediate. Hence, this lens emphasizes sustainability, resilience, and the cascading hazards of breaching ecological limits, rejecting the resettable failure states of conventional games.

Critically, the integration of planetary thresholds into geogame design raises urgent questions about responsibility and resistance against a descent into ecological collapse marked by apathy and the abandonment of collective care. This is particularly vital given the historical critique that the narrative of planetary limits risks being mobilized to justify exclusionary or anti-democratic policies, potentially reinforcing social hierarchies and systemic inequalities, rather than dismantling them. How can geogames foster a sense of accountability that transcends individual lifetimes and geographic boundaries? What ethical dilemmas arise when players must prioritize planetary health over immediate human needs? By situating planetary thresholds at the heart of gameplay, players are challenged to resist the fatalism of ecological collapse and imagine alternative futures rooted in systemic accountability, ethical governance, and regenerative solutions. This reflexive engagement transforms planetary thresholds from static limits into dynamic opportunities for learning, resistance, and transformation.

3.2. Geogames Assessment Tool

To evaluate and audit existing geogames, the study employs a rigorous methodology based on the Gaia lenses and their associated analytical categories. We created and structured an assessment tool for this analysis, categorizing games according to their alignment with the lenses and their ability to model urban–ecological dynamics. To ensure a rigorous and diverse selection of games, the methodology involved a systematic search across online platforms such as Games for Change, Games for Cities, Games4Sustainability, and Board Game Geek. Five illustrative examples were chosen for each category, reflecting a wide range of possibilities in terms of gameplay mechanics, thematic focus, and educational potential. These games were selected based on their alignment with the Gaia lenses, their ability to exemplify the Gaia-inspired analytical categories, and their relevance to real-world challenges in urban and regional planning.

The objective of our assessment tool is to move beyond conventional metrics—such as simple usability or engagement—to diagnose how effectively games embody the complexity of planetary systems. The chosen games were rigorously selected for diversity across three criteria: platform type (digital vs. analog), thematic focus (e.g., climate change, biodiversity, urban resilience), and their capacity to prefigure the Gaia lenses. This process ensured the selection of outliers that showcase alternative design philosophies, rather than the dominant SimCity-style clones. The resulting audit protocol aims to prioritize three key factors: (a) agency distribution, assessing the extent to which non-human systems influence game events; (b) temporal fidelity, evaluating how accurately ecological timescales are represented; and (c) threshold representation, examining whether collapse points are modeled as systemic rather than localized. This tool thus transforms subjective commentary into a reproducible audit protocol for diagnosing ecological coherence in games.

4. Results

The application of Gaia theory to games in architecture, urban, and regional planning marks a transformative shift in both conceptualization and practice. By embedding Gaia's systemic principles, the proposed framework directly addresses the anthropocentric limitations of conventional planning games, foregrounding the emergent, interconnected nature of urban–ecological systems. Most existing games privilege static, human-driven decision-making, often neglecting the nonlinear, co-evolutionary dynamics that characterize real-world urban environments. For example, in widely adopted city-builders like Cities: Skylines, non-human agency is often absent, and ecological collapse is modeled as a local event rather than a systemic consequence. The Gaia-inspired framework intervenes by structuring ecological complexity into the core of game design, compelling players to grapple with the ethical and systemic consequences of their actions. Equally, the same lens-lever grid can be deployed as an evaluative rubric, allowing scholars to diagnose where existing planning games illuminate—or ignore—crucial feedbacks, multispecies agencies, and planetary limits, and to quantify those omissions with reproducible metrics.

Assessing Gaia-aligned geogames requires moving beyond conventional usability metrics to evaluate how effectively they embody the complexity of planetary systems. The Gaia Assessment Tool (Table 1) aims to prioritize three key factors: (a) agency distribution, assessing the extent to which non-human systems influence game events; (b) temporal fidelity, evaluating how accurately ecological timescales are represented; and (c) threshold representation, examining whether collapse points are modeled as systemic rather than localized. While the table highlights 20 games, it acknowledges the existence of many other

relevant titles, emphasizing the breadth of this emerging field. This rigorous approach ensures that the selected games not only represent the diversity of possibilities but also serve as valuable tools for exploring the complex interdependencies between built environments and ecological systems.

Table 1. Detailed Gaia Assessment Tool.

Main Gaia Lenses	Gaia-Inspired Analytical Categories	Illustrative Games
Feedback Mechanisms: Urban–ecological loops that amplify, damp, or cascade.	Systemic Interconnectedness: Reveals the knock-on links among built and ecological environments. Feedback Loops: Tracks non-linear cause-and-effect, surfacing delayed blow-back. Resource Flow & Balance: Gauges energy/material cycles and consequences of overshoot.	Block'Hood (Plethora Project, 2017) explores intricate relationship between neighborhood influences and land use. Flood Resilience Game (Centre for Systems Solutions, 2017) simulates planning decisions and flood risks. Eco (Strange Loop Games, 2018) tracks resource cycles and ecological feedback. Underwater Cities (Delicious Games, 2018) imagines a collapsed future where humanity must master living beneath the sea. Pandemic (Z-Man Games, 2008) models global disease spread and its systemic consequences.
Co-evolutionary Dynamics: Built form & biophysical systems reshape one another over time and scale.	Temporal & Spatial Scales: Situates decisions from parcel to watershed, minute to decade. Governance & Policy Simulation: Tests how rules mutate alongside evolving ecologies. Socio-Political Agency: Who holds, shares, or loses decision-making power as urban–ecological systems evolve.	Urban Climate Architect (CliSAP, 2016) focuses on adaptive strategies for climate risks like heat islands and flooding. Play the City (Tan, 2017) simulates co-design and governance over a monopoly-like board. Videogame Urbanism (Pearson & Youkhana, 2020) fosters speculative scenarios to question power forces that shape cities. SimCity (Electronic Arts, 2013) shows policy impacts on urban growth and environment. RElastiCity (TU Delft Game Lab, 2021) emphasizes protecting cities against stresses and adapt them to become more resilient.
Multispecies Interactions: More-than-human agents hold political stakes in the city.	Biodiversity & Ecosystem Health: Values habitat networks and services within the urban fabric. Anthropocentric ↔ Ecocentric Paradigms: Challenges human-exceptionalist world-views. Ethics & Moral Implications: Foregrounds responsibility and justice across species lines.	Planet Zoo (Frontier, 2019) centres habitat design for species well-being. Tree (New Reality Company, 2017) immerses players in a tree's lifecycle. Ubuntu (Traficantes de Sueños, 2022) makes humans negotiate territory with beavers and oaks. Ego City (The Why Factory, 2014) forces densification choices under strict carbon-and-biodiversity caps. Beecarbonize (Charles Games, 2023) explores non-human agency for climate action.

Table 1. (Cont.) Detailed Gaia Assessment Tool.

Main Gaia Lenses	Gaia-Inspired Analytical Categories	Illustrative Games
Planetary Thresholds: Irreversible tipping points that bound urban futures.	Sustainability & Resilience: Probes capacity to stay within or adapt to hard limits. Planetary-Limit Focus: Monitors CO_2, groundwater, or nitrogen levels that trigger collapse states. Irreversibility & Risk: One-way tipping points and the cascading hazards that follow threshold breaches.	TRADEOFF! (Natural Capital Project, 2015) ends scenarios once nutrient thresholds break. Cities: Skylines—Natural Disasters (Paradox Interactive, 2016) tests planning under escalating shocks. Ecocraft (Hettinga et al., 2021) simulates the pursuit of clean energy. Carbon City Zero (Possible, 2020) builds carbon-neutral cities. Daybreak (CMYK, 2024) deploys policies and technologies as climate actions to dismantle the engine of global heating and to build resilient societies.

Our proposed detailed framework (Table 2) was developed through a two-step process: literature triangulation and framework synthesis. First, we cross-mapped four core Earth-system processes—nonlinear feedbacks, co-evolutionary dynamics, multispecies interactions, and planetary thresholds—with the socio-ecological questions central to contemporary urban research (Batty, 2013; Beatley, 2012; Rockström et al., 2009). Simultaneously, insights from game studies (Aarseth, 1997; Flanagan, 2009) clarified which ecological dynamics are often overlooked in city-building simulations. This triangulation produced a shortlist of "design-critical" concepts, such as delayed feedback, role symmetry between humans and non-humans, and irreversible state changes, which any Gaia-aligned geogame should address.

To ensure usability in tight design cycles, the framework was structured as a 4 × 5 grid, with four Gaia lenses (feedback mechanisms, co-evolutionary dynamics, multispecies interactions, and planetary thresholds) intersecting with five design levers (visual layer, narrative framing, procedural rules, temporal/irreversible pacing, and incentives/agency). Each cell in the framework includes a guiding sentence and an open-ended design question, inspired by Schell's (2020) "lens" strategy for rapid ideation. This approach allows the framework to function as a flexible, context-specific tool for sparking creative solutions without sacrificing theoretical depth. Additionally, an overarching educational and transformative layer evaluates how effectively gameplay reshapes real-world understanding and behavior around ecological interdependence and sustainable planning.

The detailed framework's structure is summarized in Table 2, which contrasts conventional geogames with Gaia-aligned designs.

Table 2. Detailed Gaia Design Tool.

Gaia Lens & Analytical Categories	Visual Layer (Maps, dashboards, AR overlays that make hidden flows legible)	Narrative & Storytelling (Quests, cut-scenes, or news flashes that contextualise systemic change)	Procedural Rules (Code or board mechanics that enact coupling, veto, or mutation)	Time & Irreversibility (Pacing tools that stretch or lock decisions to mirror real delays)	Incentives & Agency (Point systems, veto tokens, or playable roles that redistribute power)
Feedback Mechanisms (Systemic Interconnectedness – Feedback Loops – Resource Flow & Balance)	A composite heat-map lets one zoning change ripple across traffic, emissions, and hospital visits. "Where must colour shifts appear so players instantly grasp the knock-on?"	A delayed smog rebound becomes the Act II crisis that reframes earlier choices. "Which story beat reveals last turn's highway bond causing today's blackout?"	Hidden multipliers escalate runoff until a flood card triggers automatic district failure. "Which coefficient should secretly double impact each round?"	Air-quality recovery proceeds 10 turns after emissions fall, never instantly. "How long should the haze linger to convey real lag?"	Points accrue only when profit growth and pollution decline trend toward equilibrium. "How do we reward stability over expansion spikes?"
Co-Evolutionary Dynamics (Temporal & Spatial Scales – Governance/ Policy – Socio-Political Agency)	A zoomable layer links parcel edits to upstream watershed colour-shift. "How can a single gesture reveal street work altering regional runoff?"	A three-generation family diary tracks shifting bylaws and landscape change. "Whose descendant should pay the cost of a quick rezoning?"	Building codes mutate automatically when bat populations colonise attics. "What rule rewrites itself once a threshold of roosts is reached?"	Flood-damaged land must rest five rounds before rebuilding, mirroring soil recovery. "How long should enforced pauses last to feel ecological?"	Prestige rises when marginalised actors obtain council veto power. "Which bonus unlocks only after new voices gain a formal seat?"
Multispecies Interactions (Biodiversity & Ecosystem Health – Anthro ↔ Eco Paradigms – Multispecies Ethics & Justice)	Bee-corridor overlays flash red where pesticide spray zones overlap pollinator paths. "Which icon best flags an imminent habitat break?"	A river narrates its grievance as a mini-scene before a zoning vote. "How can non-human testimony sway players' choices?"	Tree agents wield veto tokens to cancel car-park projects when root zones shrink. "How often may a non-human veto be exercised?"	Construction freezes for three rounds during nesting season, enforcing ecological time. "What seasonal lockout best conveys breeding vulnerability?"	Victory requires raising both household income and species richness indices. "How do we prevent a win if bat counts fall?"
Planetary Thresholds (Sustainability & Resilience – Planetary-Limit Focus – Irreversibility & Risk)	A crack-line gauge turns black when CO_2 nears a tipping value. "Which visual cue screams 'point of no return'?"	Flash-forward headlines show the city five years after aquifer collapse. "What future scene will jolt players into pre-threshold action?"	Once $CO_2 > 450$ ppm, subsidies vanish and rule-sets harden, simulating a new climatic regime. "Which mechanic should flip instantly upon breach?"	Shoreline loss becomes permanent; no undo or rollback permitted. "Which decision must create an unfixable state change?"	After a breach, scoring flips from growth to harm-reduction and triage. "How will post-collapse metrics value damage limitation over profit?"

4.1. Employing the Framework as an Assessment Tool

The framework is intended to transform subjective commentary into a reproducible audit protocol. The procedure is initiated with scoping, during which the Detailed Gaia Assessment Tool (Table 1) is used as the core assessment matrix. The evaluation focuses on the smallest self-contained gameplay loop—one fiscal year in Cities: Skylines, for example—and the principal interface layer (map, board, or VR scene) is selected. Subsequently, the 20 lens-lever cells are traversed and evidence for each linkage is coded as present, partial, or absent. Visual assets (heat-maps), rule artefacts (code or card text), and behavioural logs (player choices) are employed as evidence sources. Thereafter, relevance weights (1–3) are assigned to every cell in accordance with the study brief; coastal investigations, for instance, are often weighted toward Planetary Thresholds rows. Presence scores are then multiplied by weights, and a radar plot is generated that exposes over- and under-represented ecological logics, supplemented by qualitative notes referencing the mechanics that produced each score.

When this protocol is applied to Cities: Skylines—Natural Disasters (Paradox Interactive, 2016), strong performance is recorded in Feedback-Mechanisms, because zoning changes instantly recolour congestion and pollution layers, whereas all Multispecies Interactions rows are marked absent, indicating that no agency is granted to non-human actors. By contrast, Eco (Strange Loop Games, 2018) registers high Feedback–Mechanisms scores through progressive climate loops encoded in server rules, but only partial performance in Co-Evolutionary Dynamics, given that governance statutes are not mutated by ecological change. A tabletop audit of Ubuntu (Gaidet, 2024) highlights complete Multispecies Interactions coverage via tree and beaver veto tokens, yet weak visual layers are flagged, suggesting that richer habitat overlays could be incorporated. With its live block-level input-output ledger and colour-coded flow icons that lay energy-waste links bare (strong Feedback-Mechanisms), Block'hood makes systems couplings instantly legible while its deliberately minimal story and rewards leave room for added incentive layers to deepen learning (Sánchez, 2015). In this fashion, the framework enables concrete affordances to be retained, adapted, or invented in subsequent production cycles.

Each populated cell forms a testable design claim (e.g., visible feedback loops), enabling direct evaluation via: interface logs for mechanic verification (veto triggers), pre/post concept mapping for systems thinking (Novak & Cañas, 2008), and policy support measures for Planetary Thresholds (Weber, 2015). Games strong in time-irreversibility mechanics warrant longitudinal tracking given their theorized attitudinal persistence (Bosman, 2019). By coupling clear design prompts with diagnosable outcome statements, the framework aligns with design-based-research standards (Barab & Squire, 2004) and transdisciplinary sustainability frameworks (Lang et al., 2012). This ensures that every mechanic is justified by its capacity to shift real-world understanding, aligning the tool with broader goals of durable, transformative change in urban governance.

4.2. Employing the Framework as a Design Tool

When used prospectively, the Gaia Design Tool (Table 2) is intended to function as a generative checklist that guides teams from abstract ecological concerns to concrete mechanics. A design cycle is normally initiated by the selection of a primary Gaia lens—Multispecies Interactions, for example—based on the environmental question or site context. Designers are then asked to examine the five design levers and to

draft at least one mechanic for every intersection cell. Under Multispecies Interactions, the prompt "Which non-human agent wields a veto?" may be translated into an oak-root algorithm that cancels parking garages encroaching on riparian zones. When a first sweep has been completed, a reinforcement pass is conducted to ensure that mechanics introduced by one lever are supported by complementary levers; the oak veto is thus coupled with a narrative scene in which the tree "speaks" and a visual overlay that flashes red when root zones contract.

The weighting column described in the audit protocol is subsequently reused as a development triage: High-priority yet empty cells are targeted immediately, thereby preventing feature sprawl and focusing effort on the intersections deemed essential for expressing chosen Gaia dynamics. The value of this disciplined focus is illustrated by published titles. In Planet Zoo (Frontier, 2019), a coherent Multispecies Interactions vision is achieved because mechanics, interface panels, and scoring systems all reinforce habitat welfare; in Surviving Mars (Haemimont, 2018), planetary thresholds are visualised but the procedural and incentive levers required to render dust-storm damage irreversible are absent, a gap that would have been illuminated had the framework been consulted during early concept development.

The framework can also be rotated mid-project to integrate under-represented dynamics. If a prototype is strong in Feedback Mechanisms loops, a later sprint can be devoted to Planetary-Threshold regarding limitations of time, implementing an irreversible aquifer-depletion mechanic. Because each prompt is formulated generically, the tool is transferable across media—from VR flood simulations to cardboard zoning games—consistent with Brandt's (2006) assertion that serious-game mechanics must be tailored to project goals.

An educational-and-transformative layer is intended to overarch the grid, ensuring that every mechanic is justified by its capacity to shift real-world understanding or behaviour concerning ecological interdependence and sustainable planning (Brković Dodig & Groat, 2019). Accordingly, the framework is advanced not as a rigid checklist but as a flexible, theory-rich prompt set that can be deployed for rigorous evaluation or for the construction of new, Gaia-aligned geogames.

5. Discussion

The Gaia-inspired framework marks a measurable advance in the field of geogames, moving beyond the limitations of conventional planning tools to offer a genuinely systemic and reflexive approach to urban and regional challenges. By operationalizing Gaia theory through our design framework, we foreground the entanglement of social, ecological, technological, and political processes, challenging the persistent anthropocentrism and reductionism that have long characterized both urban planning and serious game design. In doing so, we position geogames not merely as didactic simulations, but as experimental arenas where the consequences of policy, the agency of non-human actors, and the unpredictability of complex systems can be meaningfully explored and contested. This framework's critical contribution lies in its capacity to make visible and playable the feedbacks, co-evolutionary dynamics, multispecies interactions, and planetary thresholds that define contemporary urbanization. By embedding these lenses into the mechanics, narratives, and incentives of geogames, we enable designers and stakeholders to interrogate the cascading effects of decisions, the distribution of agency, and the ethical stakes of urban transformation. The framework thus serves as both a diagnostic and generative tool: It reveals where existing games

reinforce extractive, human-centered logics, and it guides the creation of new games that foreground interdependence, resilience, and justice.

Yet, the promise of the Gaia-inspired approach is matched by the complexity of its implementation. The technical demands of modeling urban–ecological systems with fidelity—integrating real data, simulating non-linear feedbacks, and representing more-than-human agency—require interdisciplinary collaboration and significant resources. Moreover, the participatory ambitions of geogames are often challenged by issues of inclusivity, accessibility, and power. While the framework can democratize planning by inviting diverse actors into the design process, it also risks reproducing existing inequities if marginalized voices are not meaningfully engaged or if the tools themselves remain inaccessible.

A further challenge lies in the translation of game-based insights into real-world planning outcomes. While geogames can foster systems thinking, scenario exploration, and stakeholder dialogue, their actual impact on policy and practice remains under-examined. To address this, we advocate for robust, mixed-methods evaluation protocols that move beyond engagement metrics to assess shifts in understanding, attitudes, and, crucially, support for systemic change. Longitudinal studies, process tracing, and comparative analyses with traditional planning methods are essential to determine whether Gaia-aligned geogames can catalyze durable change in urban governance, design, and community action.

The framework's limitations also demand critical reflection. While Gaia theory offers a powerful lens for reimagining urban systems, it may risk oversimplifying the social and political complexities that shape cities. Urban environments are not only ecological assemblages but also sites of contestation, shaped by histories of inequality, exclusion, and conflict. The Gaia metaphor, if uncritically applied, could obscure these dynamics or naturalize existing power relations. Addressing this requires ongoing theoretical innovation—integrating justice, participation, and historical consciousness into both the design and assessment of geogames.

Scalability remains another open question. While the framework has demonstrated value at the local and project scale, its application to regional or global challenges requires further methodological development. We acknowledge that governance fragmentation and ecological complexity are inherent to all scales, including the local. However, at regional and global scales, this challenge is intensified because ecological processes transcend administrative boundaries. Addressing this requires developing networked, federated game environments, and modular design strategies may offer pathways forward, but these approaches must be tested in practice.

Looking ahead, the integration of emerging technologies such as AI, virtual and augmented reality, and persistent digital twins holds promise for deepening the realism, immersion, and participatory potential of Gaia-aligned geogames. Equally, the development of accessible, non-digital formats can broaden participation and foster critical engagement beyond the digital divide. Ultimately, the true measure of this framework's success will be its capacity to provoke new forms of reflexivity, collaboration, and action among planners, designers, and communities, transforming geogames from illustrative tools into engines of urban and planetary transformation.

6. Conclusion

Our article has advanced the field of geogames by introducing the Gaia-inspired framework as both a critical lens and a practical methodology for the design and assessment of games in urban and regional planning. By embedding Gaia theory at the core of geogame development, we challenge the prevailing tendencies of planning simulations to privilege static, human-centered logics and to overlook the dynamic, interdependent realities of urban–ecological systems. The framework's insistence on systemic thinking, participatory engagement, and ecological adaptability offers a compelling pathway for addressing the urgent and intertwined crises of urban degradation, climate change, and sustainability.

Crucially, the integration of Gaia theory into geogame practice is not a mere theoretical exercise, but a necessary intervention in how we conceptualize, model, and ultimately shape urban environments. Gaia's focus on the mutual constitution of living and non-living systems reframes cities as complex, adaptive assemblages—spaces where human and more-than-human agencies are in constant negotiation. Through this lens, geogames become more than educational or participatory tools; they emerge as experimental platforms for exploring the cascading consequences of decisions, the distribution of agency, and the ethical dilemmas at the heart of urban transformation.

Yet, realizing the full potential of this framework demands a profound paradigm shift. The current geogame landscape remains fragmented, often constrained by reductionist models and short-term metrics. To confront the complexities of the Anthropocene, geogames must evolve—embracing interconnectedness, resilience, and co-evolutionary dynamics as foundational principles. This evolution is not solely a matter of technical refinement; it requires a reimagining of the cultural, institutional, and political contexts in which games are conceived and deployed. It calls for interdisciplinary collaboration, the genuine inclusion of marginalized voices, and a sustained commitment to equity and justice in both process and outcome.

As a living framework, the Gaia Design Framework is open to adaptation and expansion, evolving alongside the crises it seeks to address. Future developments could deepen its engagement with temporal scales, simulating the long-term impacts of short-term decisions, or explore more nuanced representations of multispecies agency. Beyond its immediate application to geogame design, the framework invites broader conversations about the role of geogames in shaping public discourse and urban policy. How can geogames serve as platforms for participatory urban and regional planning or as tools for fostering ecological literacy? Such questions underscore the transformative potential of the framework—not just as a design or assessment/auditing tool but as a catalyst for reimagining our cities within a fragile and interdependent world.

Ultimately, the Gaia-inspired framework is a call to action for the geogame community: to move beyond the limitations of traditional planning tools and to harness the transformative potential of play as a mode of inquiry, critique, and collective imagination. In an era defined by planetary crisis, the stakes for how we design, play, and learn from geogames could not be higher. The imperative is clear: Only by radically rethinking our approaches can we hope to foster the sustainable, resilient, and just urban futures our world so urgently requires.

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References

Aarseth, E. (1997). *Cybertext: Perspectives on ergodic literature*. Johns Hopkins University Press.

Adams, E. (2014). *Fundamentals of game design* (3rd ed.). New Riders.

Ahlqvist, O., & Schlieder, C. (2018). *Geogames and geoplay*. Springer. https://doi.org/10.1007/978-3-319-22774-0

Andrade, B., Braga, L. I., & Cunha, C. A. (2024). The city as a cosmopolitical board game: Candomblé terreiros in Bahia, atmospheres, and design games. In M. Boubezari, C. R. Duarte, & E. Pinheiro (Eds.), *Proceedings of the 5th International Congress on Ambiances—Sensory Explorations: Ambiances in a Changing World* (pp. 326–339). International Ambiances Network.

Andrade, B., & Pereira Roders, A. (2022). Value-based redesign in gamified learning environments. In R. Rocco, A. Thomas, & M. Novas-Ferradás (Eds.), *Teaching design for values: Concepts, tools & practices* (pp. 292–317). TU Delft OPEN Publishing.

Barab, S. A., & Squire, K. (2004). Design-based research: Putting a stake in the ground. *Journal of the Learning Sciences*, *13*(1), 1–14. https://doi.org/10.1207/s15327809jls1301_1

Batty, M. (2007). *Cities and complexity: Understanding cities with cellular automata, agent-based models, and fractals*. MIT Press.

Batty, M. (2013). *The new science of cities*. MIT Press.

Beatley, T. (2012). *Biophilic cities: Integrating nature into urban design and planning*. Island Press.

Bosman, F. G. (2019). There is no solution!: "Wicked problems" in digital games. *Games and Culture*, *14*(4), 347–364.

Brandt, E. (2006). Designing exploratory design games: A framework for participation in participatory design? In *PDC '06: Proceedings of the Ninth Conference on Participatory Design: Expanding Boundaries in Design—Volume 1* (pp. 57–66). Association for Computing Machinery. https://doi.org/10.1145/1147261.1147271

Brković Dodig, M. B., & Chiles, P. (2016). 'Spector—The sustainability inspector': Participatory teaching, learning and evaluation game for architects, architecture students and pupils. *Facta Universitatis—Series: Architecture and Civil Engineering*, *14*(1), 1–20. https://doi.org/10.2298/FUACE1601001B

Brković Dodig, M. B., & Groat, L. (2019). *The Routledge companion to games in architecture and urban planning: Tools for design, teaching, and research*. Routledge.

Centre for Systems Solutions. (2017). *Flood Resilience Game* [Video game]. https://floodresilience.socialsimulations.org

Charles Games. (2023). *Beecarbonize* [Video game]. https://www.charlesgames.net/beecarbonize

CliSAP. (2016). *Stadt Klima Architekt* [Video game]. https://www.cen.uni-hamburg.de/press/entdecken/stadtklimaarchitekt.html

CMYK. (2024). *Daybreak*. https://www.daybreakgame.org

Delicious Games. (2018). *Underwater Cities*. Board Game Geek. https://boardgamegeek.com/boardgame/247763/underwater-cities

Despret, V. (2016). *What would animals say if we asked the right questions?* University of Minnesota Press.

Doolittle, W. F. (2019). Making evolutionary sense of Gaia. *Trends in Ecology & Evolution*, *34*(10), 889–894. https://doi.org/10.1016/j.tree.2019.05.001

Duke, R. D. (1974). *Gaming: The future's language*. Sage.

Electronic Arts. (2013). *SimCity* [Video game]. https://www.ea.com/games/simcity/simcity

Fernández Galeote, D., & Hamari, J. (2021). Game-based climate change engagement: analyzing the potential of entertainment and serious games. *Proceedings of the ACM on Human-Computer Interaction*, *5*(CHI PLAY), Article 226.

Flanagan, M. (2009). *Critical play: Radical game design*. MIT Press.

Frasca, G. (2003). Simulation versus narrative: Introduction to ludology. In M. J. P. Wolf & B. Perron (Eds.), *The video game theory reader* (pp. 221–235). Routledge.

Frontier. (2019). *Planet Zoo* [Video game]. https://www.planetzoogame.com

Gaidet, N. (2024). Composer un territoire de vie en commun entre humains et non-humains : l'exemple du jeu Ubuntu. In *Jeux & Enjeux Proceedings* (pp. 132–134). Maison des Sciences de l'Homme de Montpellier.

Haraway, D. J. (2016). *Staying with the trouble: Making kin in the Chthulucene*. Duke University Press.

Hettinga, S., Boter, J., Dias, E., Fruijtier, S., de Vogel, B., & Scholten, H. (2021). Urban energy transition in a gaming context: The role of children. *Land Use Policy*, *111*, 104903.

Haemimont Games. (2018). *Surviving Mars* [Video game]. Paradox Interactive. https://www.haemimontgames.com/games/surviving-mars/

Juul, J. (2005). *Half-real: Video games between real rules and fictional worlds*. MIT Press.

Lang, D. J., Wiek, A., Bergmann, M., Stauffacher, M., Martens, P., Moll, P., Swilling, M., & Thomas, C. J. (2012). Transdisciplinary research in sustainability science: Practice, principles, and challenges. *Sustainability Science*, *7*(Suppl. 1), 25–43.

Latour, B. (2017). *Facing Gaia: Eight lectures on the new climatic regime*. Polity Press.

Lovelock, J. (2000). *Gaia: A new look at life on Earth* (3rd ed.). Oxford University Press.

Lovelock, J. (2006). *The revenge of Gaia: Earth's climate crisis & the fate of humanity*. Basic Books.

Lovelock, J., & Margulis, L. (1974). Atmospheric homeostasis by and for the biosphere: The Gaia hypothesis. *Tellus*, *26*(1/2), 2–10. https://doi.org/10.3402/tellusa.v26i1-2.9731

Margulis, L. (1998). *Symbiotic planet: A new look at evolution*. Basic Books.

Mayer, I. S., van Bueren, E. M., Bots, P. W. G., van der Voort, H., & Seijdel, R. (2005). Collaborative decisionmaking for sustainable urban renewal projects: A simulation–gaming approach. *Environment and Planning B: Planning and Design*, *32*(3), 403–423.

Natural Capital Project. (2015). *TRADEOFF!* [Video game]. https://tradeoffgames.naturalcapitalproject.org

New Reality Company. (2017). *Tree*. https://www.treeofficial.com

Nixon, R. (2011). *Slow violence and the environmentalism of the poor*. Harvard University Press.

Novak, J. D., & Cañas, A. J. (2008). *The theory underlying concept maps and how to construct and use them* (Technical Report IHMC CmapTools 2008-01). Institute for Human and Machine Cognition. https://cmap.ihmc.us/docs/theory-of-concept-maps

Paradox Interactive. (2016). *Cities: Skylines—Natural Disasters* [Video game]. https://www.paradoxinteractive.com/games/cities-skylines/add-ons/cities-skylines-natural-disasters

Pearson, L., & Youkhana, S. (2020). Videogame urbanism: Using game spaces to challenge the future of cities. *The Site Magazine*, *40*(3). https://www.thesitemagazine.com/read/videogame-urbanism

Plethora Project. (2017). *Block'hood* [Video game]. https://www.plethora-project.com/blockhood

Poplin, A., Andrade, B., & de Sena, Í. S. (2020). Geogames for change: Cocreating the future of cities with games. In D. Leorke & M. Owens (Eds.), *Games and play in the creative, smart and ecological city* (pp. 64–93). Routledge.

Poplin, A., Kerkhove, T., Reasoner, M., Roy, A., & Brown, N. (2017). Serious geogames for civic engagement in urban planning: Discussion based on four game prototypes. In C. Yamu, A. Poplin, O. Devisch, & G. De Roo (Eds.), *The virtual and the real in planning and urban design* (pp. 189–213). Routledge.

Possible. (2020). *Carbon City Zero*. Board Game Geek. https://boardgamegeek.com/boardgame/288179/carbon-city-zero

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., III, Lambin, E. F., Lenton, T. M., Scheffer, M., Folke, C., Schellnhuber, H. J., Nykvist, B., de Wit, C. A., Hughes, T., van der Leeuw, S., Rodhe, H., Sörlin, S., Snyder, P. K., Costanza, R., Svedin, U., . . . Foley, J. A. (2009). A safe operating space for humanity. *Nature*, *461*(7263), 472–475.

Sánchez, J. L. S. (2015). Block'hood—Developing an architectural simulation video game. In B. Martens, G. Wurzer, T. Grasl, W. E. Lorenz, & R. Schaffranek (Eds.), *Real Time—Proceedings of the 33rd eCAADe Conference* (Vol. 1, pp. 89–97). Vienna University of Technology. https://doi.org/10.52842/conf.ecaade.2015.1.089

Sanoff, H. (1979). *Design games*. William Kaufmann.

Schell, J. (2020). *The art of game design: A book of lenses* (3rd ed.). CRC Press.

Sousa, M. (2024). The Stakeholders Clash Game: From Board game design to online collaborative platforms for urban planning. In A. Marto, R. Prada, P. Gouveia, R. Contreras-Espinosa, A. Gonçalves, E. Abrantes, & R. Ribeiro (Eds.), *International Conference on Videogame Sciences and Arts* (pp. 55–69). Springer Nature.

Steffen, W., Richardson, K., Rockström, J., Cornell, S. E., Fetzer, I., Bennett, E. M., Biggs, R., Carpenter, S. R., de Vries, W., de Wit, C. A., Folke, C., Gerten, D., Heinke, J., Mace, G. M., Persson, L. M., Ramanathan, V., Reyers, B., & Sörlin, S. (2015). Planetary boundaries: Guiding human development on a changing planet. *Science*, *347*(6223), Article 1259855.

Stengers, I. (2015). *In catastrophic times: Resisting the coming barbarism*. Open Humanities Press.

Strange Loop Games. (2018). *Eco* [Video game]. https://play.eco

Tan, E. (2017). *Play the city: Games informing the urban development*. Jap Sam Books.

The Why Factory. (2014). *Ego City*. https://thewhyfactory.com/output/ego-city

Traficantes de Sueños. (2022). *Ubuntu*. https://traficantes.net/libros/ubuntu

Tsing, A. L. (2015). *The mushroom at the end of the world: On the possibility of life in capitalist ruins*. Princeton University Press.

TU Delft Game Lab. (2021). *RElastiCity: An Urban Resilience Game* [Video game]. https://seriousgaming.tudelft.nl/games/relasticity

Weber, E. U. (2015). Climate change demands behavioral change: What are the challenges? *Social Research: An International Quarterly*, *82*(3), 561–580. https://doi.org/10.1353/sor.2015.0050

Z-Man Games. (2008). *Pandemic*. https://www.zmangames.com/game/pandemic

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