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Geogame-Based Simulation for Active Mobility Planning in Socially Sustainable Cities

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Abstract

The tendency to simplify urban complexity in planning, without considering diverse social and geographical contexts, can exacerbate the urban mobility crisis. Within this paradigm, geogames offer geospatial, collaborative, playful, and inclusive means of evaluating sustainable urban design projects. To achieve the main objective of this study—namely, integrating game-based simulation into an interconnected dual-geogame framework—Cities: Skylines (C:S) was employed to model the city of Concepción. An initial calibration geogame, Scenario A, facilitated an expert-led diagnostic process through visualisation and exploration. Based on these findings, a participatory neighbourhood scenario (B) was designed to support active mobility planning, incorporating alternatives proposed by citizens during the Covid-19 pandemic. This model assessed quantitative changes in agents' modal shift preferences. Technically, C:S integrates agent-based modelling to evaluate mobility impacts within a simulated urban environment. The results informed a second geogame, where the scenario (B) was presented and refined through collaborative co-creation with undergraduate students. Through this process, alternative interventions were negotiated, adjusted for post-pandemic relevance, and enriched through consensus. Students successfully co-designed an improved version of the neighbourhood—Scenario C—focused on enhancing active mobility. These findings suggest that geogame-based simulation can reduce uncertainties associated with agent preference shifts within C:S and facilitate consensus-building for socially sustainable urban projects. The geogame framework contributes to developing a systemic, geospatial, playful, and inclusive approach to real-world urban planning, providing valuable insights for the planning and design of future socially sustainable cities.

Keywords

active mobility; game-based simulation; geogames; participatory urban design; sustainable urban planning

1. Introduction

1.1. Planning Urban Systems and Active Mobility

The rational understanding of cities has evolved towards open, self-organising, and complex systems (Portugali, 2000). Urban planning based on functional simplification has led to critical issues such as excessive land consumption, car dependency, the loss of public spaces, and urban fragmentation (Jirón & Mansilla, 2014). Furthermore, there remains a lack of specific measures to mitigate the negative effects of conventional mobility planning in addressing complex urban challenges (Jirón & Rivas, 2020), as well as a limited adoption of proximity-based strategies that foster more inclusive and socially resilient cities (Guzmán et al., 2024; Ramírez-Saiz et al., 2022). From a systems perspective, sustainable urban mobility (SUM) can be structured to promote healthy, walkable environments, integrating proximity-based solutions and accessible transport options for longer journeys. During the Covid-19 pandemic, mobility restrictions revealed higher satisfaction with sustainable short-distance travel (Núñez Cerda et al., 2024), reinforcing the importance of strategies that encourage active mobility (AM; Haufe et al., 2016; Markvica et al., 2020). This highlights the need for compact urban environments that enhance accessibility to everyday activities, countering fragmented urbanisation models that perpetuate unsustainable travel habits (Núñez, Albornoz, Gutiérrez, & Zumelzu, 2022). Against this backdrop, urban accessibility is a key factor in connecting people with activities. Its sustainable management in urban planning requires removing barriers that limit access—not only related to transport but also to urban and socio-cultural factors. In this regard, considering citizens' perceptions is essential to promoting AM (Guzmán et al., 2024). Within the framework of sustainable urban planning (SUP), public participation is a fundamental component in the development of sustainable strategies. Citizen consultations enable the identification of perceived alternatives and the promotion of satisfactory travel experiences that prioritise AM over motorised transport (Núñez, Albornoz, Gutiérrez, & Zumelzu, 2022; Núñez Cerda et al., 2024). This opens new opportunities for the implementation of collaborative methodologies that facilitate solutions within the complex political systems in which cities evolve (Mayer et al., 2005). In this participatory context, urban design approaches must become more communicative and inclusive, particularly in response to the digital transformation accelerated by the Covid-19 pandemic (Wang & Vu, 2023).

1.2. Geogame-Based Simulation for SUP

Academic urban simulation is a key digital tool in urban planning (Ruiz-Tagle, 2007; Ruiz-Tagle et al., 2009; Waddell, 2002), which has recently been integrated into video games as an innovative approach to analysis, representation, experimental decision-making, and negotiation (Mayer et al., 2004, 2005; Poplin, 2011). Game-based simulations offer significant advantages, particularly through the use of agent-based modelling (ABM; Bilal et al., 2025; González-Méndez et al., 2021; Juraschek et al., 2017; Piňos & Burian, 2022; Piňos et al., 2020; Prajapati et al., 2023), which enables the testing of urban design strategies and the assessment of their impact on a simulated society (Cartes-Siade et al., 2024, p. 122). However, their main limitation lies in the weak integration of scientific datasets, which prevents game-based simulations from achieving the analytical depth of digital twins or GIScience-based ABM. Digital twins and GIScience-based ABM, by contrast, systematically incorporate real-world data, albeit with methodological and operational constraints that must be addressed (Ribeiro-Rodrigues & Bortoleto, 2024; Weil et al., 2023). Mitigating these shortcomings requires tackling challenges that ensure effective communication among stakeholders, which represents a medium- to long-term process with implementation and funding difficulties, particularly in the Global South. An innovative strategy to bridge this gap is the integration of game-based methodologies that foster participatory urban planning (Hudson-Smith & Shakeri, 2022; Poplin, 2011). In this context, geogames emerge as a key tool for communication and stakeholder engagement due to their inclusive and playful nature (Poplin et al., 2020), with simulation being one of their most distinctive features (Ahlqvist & Schlieder, 2018). Geogames, defined as digital tools that combine geospatial elements with game mechanics, facilitate public participation in urban decision-making processes. Their potential lies in their ability to integrate interactive dynamics with real-time spatial data, allowing participants to explore, evaluate, and modify urban scenarios intuitively. These methodologies promote a collective understanding of urban space by actively involving different stakeholders in its construction and analysis (de Andrade et al., 2020; Poplin et al., 2020, 2022; Poplin & Vemuri, 2018; Vieira & Coutinho, 2016).

1.3. Research Gap in Participatory Geogames

However, there is currently no evidence of integrating game-based simulation strategies with systemic quantitative data within the framework of participatory geogames, specifically aimed at strengthening AM. This gap presents a pioneering opportunity at the global level for the development of geogame methodologies that combine game-based simulation with the geospatial, playful, and inclusive characteristics of geogames. Such an approach could extend its applicability across different phases of SUP (Poplin et al., 2020; UN-Habitat, 2007). In this context, we hypothesise that it is feasible to incorporate urban data into geogames through game-based simulation approaches, thereby establishing a direct link between playful urban design and the promotion of AM. Accordingly, our main research question was: How can various geogames created with quantitative game-based simulations be interconnected across different phases of SUP? To address this question, the objective of this study is to design and evaluate a dual-geogame methodology that integrates playful, game-based urban simulation into participatory planning processes, thereby contributing to socially sustainable AM and informed urban decision-making. The implementation of interconnected geogames via game-based simulation in Cities: Skylines (C:S) may thus facilitate the quantitative interpretation and systemic, geospatial, playful, and inclusive co-creation of sustainable urban futures.

Following this introduction, the article is structured in five sections. Sections 2 and 3 introduce the theoretical framework, which situates the study within complex urban systems and sustainable planning approaches to address AM based on user preferences, while also reviewing emerging tools for SUP, with a particular focus on general game-based methods, game-based simulations, and geogames as participatory instruments for city-making. Section 4 describes the methodological design, which implements dual geogames integrating C:S into the SUP process, first with experts and subsequently with students, to evaluate perceptions and strategies for AM. Section 5 presents the results and discussion, which highlight the potential of dual geogames to visualise, negotiate, and redesign SUM scenarios, thereby bridging quantitative data with participatory governance. Finally, Section 6 presents the conclusions, which suggest that geogame-based simulation represents an emerging approach for advancing SUP and SUM policies for AM, while also enhancing public engagement in urban transformation.

2. Systemic Urban Planning

Urban planning is based on the interaction between urbanisation and development, adopting a systemic perspective in which multiple urban subsystems are articulated through everyday mobility practices and social dynamics (Jirón & Mansilla, 2014). However, contemporary planning has tended to simplify urban complexity, promoting fragmented and highly specialised models characterised by multiple functional centres that are spatially disconnected. This extreme specialisation, rather than fostering territorial cohesion, has exacerbated spatial inequalities and restricted equitable access to urban opportunities, all within a framework of political and social complexity (Mayer et al., 2005). This territorial organisation has prioritised economic accumulation over urban transformation, displacing citizens from the construction of their environment and limiting their participation in decision-making processes (Jirón & Rivas, 2020). In response to this issue, a bottom-up approach to urban planning has been proposed as an alternative to the traditional top-down model (Semeraro et al., 2020). A model incorporating this perspective is SUP, which integrates communication mechanisms, and playful, inclusive citizen participation (UN-Habitat, 2007). This approach becomes even more relevant in contexts of high urban mobility uncertainty, where factors such as health crises and climate change impact urban sustainability and decision-making (Chondrogianni & Karatzas, 2023; Le Gouais et al., 2023).

2.1. The "Unsustainability" of Mobility

The fragmented urbanisation model has led to a crisis of urban unsustainability, driven by the dominance of modernity in shaping contemporary metropolises (Escudero, 2017; Jirón & Rivas, 2020; Nijkamp & Kourtit, 2013). This process has reinforced the proliferation of the automobile as the dominant mode of transport, with negative social, economic, and environmental impacts, including the functional simplification of urban space, energy depletion, the reduction of public spaces, noise pollution, and air pollution (Becker et al., 2020; Ruiz, 2002; Tromaras et al., 2019). In the short term, the unsustainability of urban accessibility is exacerbated by factors such as rapid population growth, uncontrolled urban land expansion, and the development of environments that exceed walkable distances (Huang et al., 2010; Rahman, 2016). Additionally, dissatisfaction with urban landscape quality discourages AM, affecting quality of life and social well-being by generating stress, segregation, and a heightened perception of urban insecurity (Nijkamp & Kourtit, 2013; Núñez Cerda et al., 2024; Zumelzu & Herrmann-Lunecke, 2021). The Covid-19 pandemic further exacerbated this scenario by paralysing urban mobility and restricting access to essential activities, disrupting travel habits and revealing the lack of viable alternatives in many cities (Arias-Molinares et al., 2022; López-Soler et al., 2023; Vega-Gonzalo et al., 2023). However, in consolidated neighbourhoods with access to essential services, urban proximity enhanced satisfaction with pedestrian mobility, reinforcing the need to advance towards proximity-based urban models (Núñez, Albornoz, Gutiérrez, & Zumelzu, 2022). Designing cities for SUM requires not only environmental considerations but also economic and social dimensions aimed at ensuring equitable and efficient accessibility within the urban system (León et al., 2019; Núñez, Albornoz, León, & Zumelzu, 2022). In this regard, tools such as social geomarketing can contribute to identifying demand patterns and designing accessibility strategies aligned with the real needs of the population, thereby promoting AM and fostering a more inclusive, sustainable, and healthy urban planning approach (Haufe et al., 2016; Kong et al., 2024; Markvica et al., 2020; Papageorgiou et al., 2024).

2.2. Social Geomarketing and AM

Social geomarketing emerges as a key tool for analysing citizens' stated needs (Albornoz et al., 2020) and their level of (dis)satisfaction with urban mobility (Núñez, Albornoz, Gutiérrez, & Zumelzu, 2022; Núñez Cerda et al., 2024). In this regard, urban accessibility, understood as a service, can present differentiated barriers depending on sociodemographic segments, highlighting the importance of studying accessibility perception and its impact on everyday mobility (Evans, 2015; Jirón & Mansilla, 2013; Núñez, Albornoz, León, & Zumelzu, 2022). Analysing citizens' perceptions of accessibility and sustainable travel enables the identification of conditions that encourage the retention of walking as a primary mode of urban mobility (Herrmann-Lunecke et al., 2020; Zumelzu et al., 2022). In this context, citizen consultations facilitate the identification of barriers and sustainable alternatives, promoting strategies to mitigate dissatisfaction and consolidate sustainable AM travel habits in line with individuals' modal intentions (Rejeb et al., 2023). Satisfaction with perceived accessibility is crucial for evaluating urban design and guiding its revitalisation, strengthening the relationship between urban well-being and minimum socially acceptable conditions of walkable neighbourhoods (Yuen et al., 2024). Additionally, this approach could help address the democratic deficit within complex systems theory, enabling the evolution of urban systems through participatory processes (Rodríguez, 2018). Within this framework, integrating playful and inclusive methodologies, such as game-based methods and geogames, represents an innovative opportunity to incorporate citizen-driven alternatives into the design of sustainable neighbourhoods. This approach could foster AM and SUP within the broader concept of healthy cities that promote mental well-being (Herrmann-Lunecke et al., 2021; Zumelzu et al., 2022, 2024).

3. Game-Based Methods

For citizen consultations to serve as an effective input in urban design and contribute to residents' satisfaction, urban planners require innovative tools that strengthen participatory processes, enhance communication, and foster collaboration (Devisch, 2008). Three categories of immersion have been identified in technological approaches to public participation: challenge-based, sensory, and imaginative. Methods such as GIS, computer-aided design, planning support systems, virtual environments, and digital games can facilitate immersion in one or more of these categories (Gordon et al., 2011; Sousa, 2023). The use of game mechanics to encourage public participation and urban decision-making has been consolidated under the concept of gamification, where video games and playful approaches are applied in non-recreational contexts (Krath et al., 2021; Muehlhaus et al., 2023; Tan, 2022). However, debate persists regarding the psychological and learning mechanisms underpinning gamification, particularly in its actual effectiveness for participation and urban decision-making. In this regard, game-based approaches have advanced the integration of playful strategies with urban planning and sustainable design methodologies, offering new opportunities to support public participation and decision-making (Hammady & Arnab, 2022; Krath et al., 2021; UN-Habitat, 2007).

3.1. Game-Based Urban Simulation

Game-based strategies integrate playful approaches into urban planning, bridging digital simulation and participatory decision-making (Poplin, 2011). Digital technologies should enhance urban analysis rather than serve as ends in themselves (Hudson-Smith & Shakeri, 2022). Urban simulation is vital for understanding complex systems and reducing planning uncertainties. Cartes-Siade et al. (2024, p. 122) suggest that game-based simulation can be used to analyse the city as a set of interconnected subsystems and may be directly integrated into analyses of SUM and accessibility (Núñez, Albornoz, Gutiérrez, & Zumelzu, 2022; Núñez Cerda et al., 2024). Within these, artificial societies explore with ABM micro-spatial mechanisms shaping macro-scale urban dynamics (Bersini, 2012; Vélez, 2019). ABM, as an analytical tool for smaller administrations (Mueller et al., 2018), deepens understanding of mobility challenges rather than predicting exact urban dynamics. It also enables empirical and participatory validation of urban scenarios via bottom-up simulation. This supports refining SUP strategies, integrating citizen participation and urban resilience. In this context, game-based simulation offers an innovative approach to training urban planners, enabling the visualisation and analysis of complex territorial dynamics (Andhika & Anggita, 2022; Roy, 2019). While widely used in geographic and urban education (Arnold et al., 2019; Khan & Zhao, 2021; Minnery & Searle, 2014; Robinson et al., 2021; Ruiz-Tagle & Gurovich, 2007; Senior et al., 2023), their integration into participatory planning remains limited. Hudson-Smith and Shakeri (2022) argue that the low adoption of these approaches is not primarily due to technical limitations but rather to how these tools have been interpreted within the dominant narratives of urban planning, which has hindered their integration into decision-making processes. Nevertheless, exploratory experiences have emerged, demonstrating the potential of urban active game-based simulation in territorial planning, with applications in urban design, policy evaluation, and mobility analysis (Bello-Maldonado, 2019; Jolly & Budke, 2023; Juraschek et al., 2017; Kavouras et al., 2023; Koens et al., 2020; Liu et al., 2021; Olszewski et al., 2020; Piňos & Burian, 2022; Piňos et al., 2020; Raghothama et al., 2022; Roumpani, 2022; Tan, 2022).

3.2. Limitations of Urban Simulation Video Games

Despite their potential in urban planning, game-based simulations have been criticised for their limitations in scientific, participatory, and inclusive contexts. Comparisons between SimCity 4 and CityLife with urban modelling tools reveal that, although these games share principles with scientific approaches, their principal limitation is the lack of flexibility to adjust simulation parameters after observation and learning (Rufat & Ter Minassian, 2012). Another issue is the absence of mixed land use in early versions of SimCity—a deficiency that persists in more recent editions (Bereitschaft, 2015). Moreover, most commercial city-building games adopt a top-down, governance perspective that privileges a single decision-maker, thereby oversimplifying the multi-actor nature of real-world planning (Bereitschaft, 2015; Raghothama et al., 2022). Intellectual property constraints also present a challenge, as proprietary code often turns simulation logic into a "black box," where rules must be inferred through gameplay rather than explicitly understood (D'Artista & Hellweger, 2007; Devisch, 2008). Nevertheless, such restrictions can be mitigated through modding—a process that modifies game behaviour using custom scripts (Scacchi, 2010; Sotamaa, 2010). C:S exemplifies this potential, as its active modding community has created tools ranging from cosmetic enhancements to advanced extensions in geographic and agent-based simulation, enabling forms of virtual geoplay through highly realistic urban recreations (Olszewski et al., 2020; Piňos et al., 2020). While C:S is not a serious game by design, it can be employed within a game-based simulation framework consistent with the paradigm of serious applications of games in participatory urban planning (Poplin, 2011).

3.3. C:S

C:S utilises an ABM framework to simulate citizen and vehicle behaviour in dynamic urban environments, representing cities as self-organising systems where agent interactions generate emergent urban phenomena (Juraschek et al., 2017; Portugali, 2000). From an ABM perspective, each resident in C:S functions as an autonomous agent, meaning that their movements, activities, and decisions influence the configuration of the virtual urban system. These interactions can be affected both by the actions of other agents and by the geographical conditions of the environment (Bersini, 2012; Bilal et al., 2025; González-Méndez et al., 2021; Piňos et al., 2020; Prajapati et al., 2023). The ability to experiment with these models enables the simulation of complex urban dynamics and the evaluation of environmental, economic, and social sustainability scenarios (Jolly & Budke, 2023; Juraschek et al., 2017). These immersive and participatory strategies have been applied in urban planning with the support of residents, authorities, and academics, as well as in educational settings (Andhika & Anggita, 2022; Olszewski et al., 2020; Shi et al., 2025). From a methodological perspective, geoplay emerges as a key approach within serious geogames, allowing users to experiment with urban scenarios, modify environmental elements, and co-create urban solutions based on real data (Ahlqvist & Schlieder, 2018; Poplin et al., 2022). While C:S is a valuable tool for game-based simulations within the context of geoplay, it has limitations in acquiring real-time data and spatially representing scientific indicators, restricting its applicability in participatory processes compared to GIS-based ABM models and urban digital twins (Crooks et al., 2019; Heppenstall et al., 2012; Mohammadi & Taylor, 2017). However, various scholars highlight that these tools also face challenges, such as cost, accessibility, and the scalability of their models in diverse urban contexts (Ribeiro-Rodrigues & Bortoleto, 2024; Weil et al., 2023). Overcoming these limitations requires addressing scientific and technical challenges while ensuring collaboration between citizens, academia, and local stakeholders. In the Global South, where resources for technological development may be limited, geogames offer an accessible and innovative alternative to fostering participation in SUP.

3.4. Geogames

In a digital context, geogames are games that integrate real geospatial information and GIS-based technologies to mediate the gaming experience. According to Ahlqvist and Schlieder (2018), they combine geographic data with spatial principles in their mechanics and dynamics, establishing a direct link with urban simulation. Both approaches share the representation of spatial systems, incorporating key concepts such as location, distance, networks, and granularity, which are essential for modelling interactions between actors and urban elements. Unlike purely quantitative theoretical urban simulations (Ruiz-Tagle et al., 2009; Waddell, 2002), geogames enable direct experimentation with the urban environment, facilitating participatory planning and real-time analysis of urban dynamics. Additionally, they can be used for urban scenario modelling, allowing players to explore development alternatives, test urban policies, and simulate infrastructure before its real-world implementation. From a participatory perspective, Poplin et al. (2020, 2022) highlight that geogames not only integrate geospatial information but also promote the co-creation of urban environments, particularly among younger populations. In this context, the novelty of geogames within the gaming sphere, through various forms of interaction (de Andrade et al., 2020), suggests a strengthening of their connection with playful urban simulation. This is achieved through the exploration of digital environments, experimentation with urban models, and the gamification of decision-making processes, positioning geogames as innovative tools for education, citizen participation, and urban planning (Shakeri, 2022).

From the theoretical review, we identify a key gap in the integration of systemic quantitative data from game-based simulations within participatory geogames, particularly in their application to the design of urban scenarios that promote AM. Currently, no methodology links game-based urban simulation with the geospatial and playful interaction of geogames while simultaneously incorporating parameters derived from citizens' everyday experiences and validated by local stakeholders in planning and design. This absence represents a pioneering opportunity to explore how dual geogames integrating systemic quantitative data from game-based simulations can serve as tools for SUP. In this regard, we propose the use of C:S as an immersive and participatory platform for new geogames, integrating citizen consultation data to evaluate impacts on urban system sustainability. The central challenge is to consolidate an interconnected dual-geogame strategy applicable to SUP, enabling stakeholders to geoplay with urban scenarios, test AM policies, and analyse their effects in a quantifiable manner. Such an approach may contribute to reducing uncertainties in urban decision-making. In the short term, this methodology suggests the potential to provide innovative tools for planning proximity-based cities, healthier urban environments, and AI-enabled smart cities in the Global South, positioning geogame-based simulation as a promising component of sustainable, systemic, playful, and inclusive urban planning.

4. Methodology

The methodology is based on a proof of concept that examines the integration of game-based urban simulation as a tool for developing an interconnected dual-geogame framework (Figure 1). The method follows a sequential approach, beginning with the initial game-based simulation, its calibration and validation through the first geogame, and its iterative refinement throughout the study. Initially, urban game-based simulation data are analysed to assess their geospatial and urban accuracy by comparing them with real-world conditions. These data are then adjusted through the first geogame iteration. Subsequently, intermediate results emerge from the initial negotiation and consensus-building phase, serving as inputs for the second geogame. In this stage, participants explore and negotiate modifications to the urban design, ultimately reaching a final consensus that informs the development of an urban project aimed to promote AM as an input for SUP. The planning of both geogames is provided in the Supplementary File.

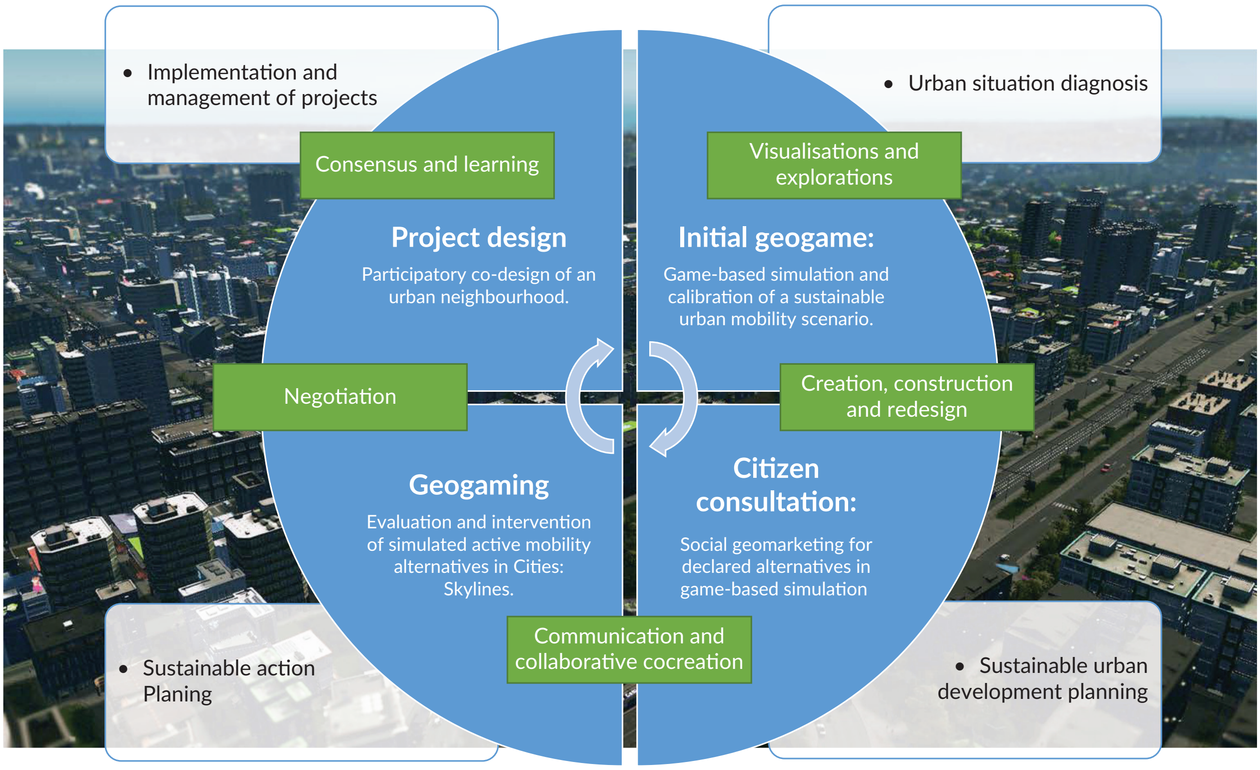

Figure 1. SUP phases: Geogame-based methodology. Note: Dual-geogame interconnected components (blue), according to the main stages of the geogame (green), supporting the different phases of SUP (white).

4.1. Case Study: The Collao Neighbourhood

Collao is a neighbourhood in Concepción, one of the municipalities of the Metropolitan Area of Concepción. It is located approximately 2 km northeast of the city centre and comprises seven housing estates, as well as the University of Bío-Bío. Núñez Cerda et al. (2024) characterise Collao as a homogeneous residential neighbourhood, defined by predominantly detached housing interspersed with medium-rise isolated buildings, front gardens, and open green spaces (Figure 2a). Its geographic condition makes this territorial unit particularly relevant for this study. The area is characterised by a degree of geographic isolation caused by the remnants of the coastal mountain range, and is bounded to the east by the Nonguén stream. As a result, its connectivity relies solely on the Collao–Novoa road system. This contrasts with other sectors of the Metropolitan Area of Concepción, whose connectivity is shaped by a geometrically organised street network based on the gridiron plan (Figure 2b). Building on this contextual overview of Collao, the next step was to operationalise these urban characteristics through an initial game-based simulation in C:S.

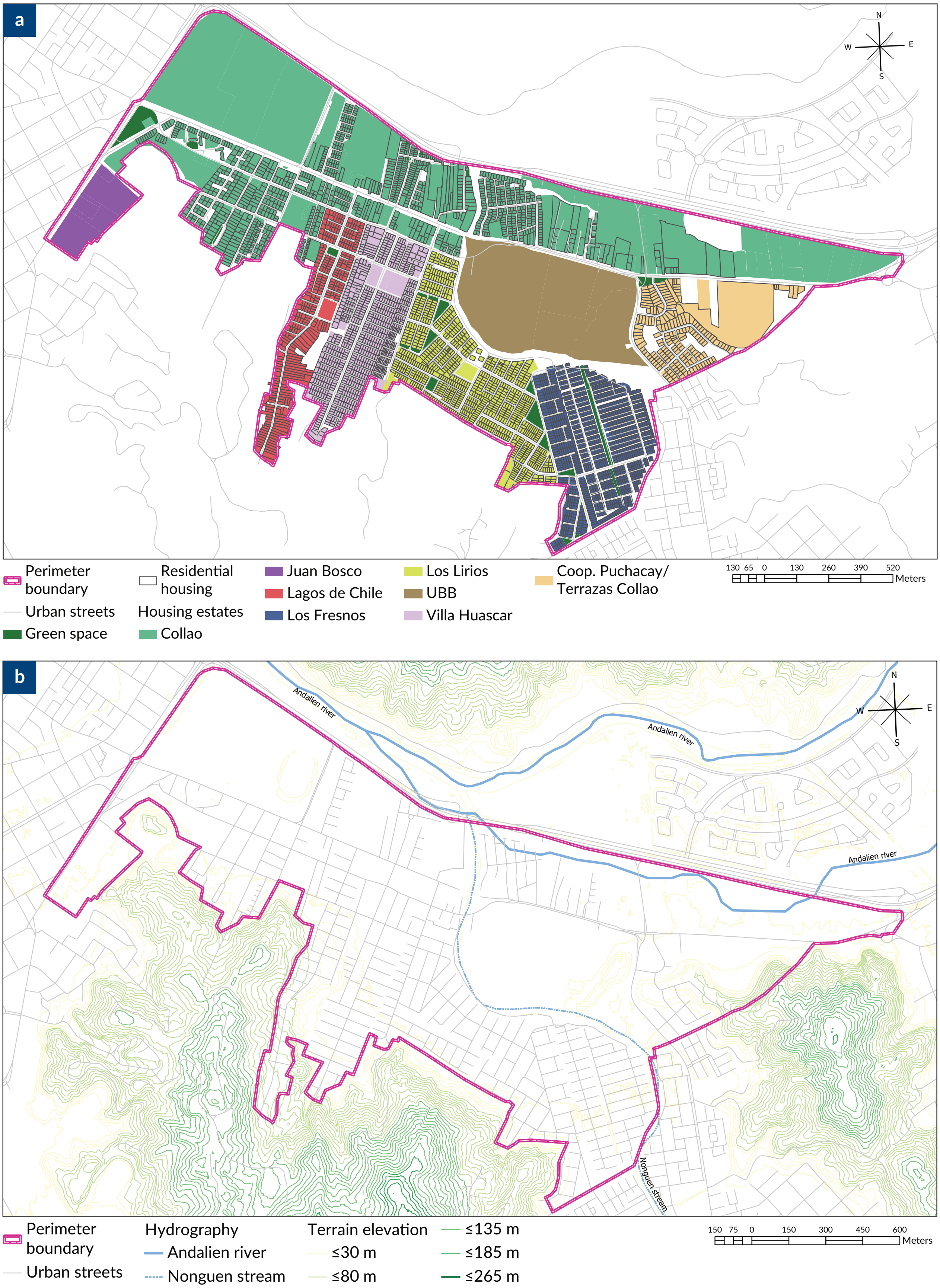

Figure 2. Collao neighbourhood: (a) urban profile; (b) geographic profile.

4.2. Initial Game-Based Simulation of Concepción With C:S

To integrate game-based simulation as a methodological tool within geogames, the city of Concepción was modelled in C:S with mods (Table 1). C:S was selected as the game-based simulation engine due to its modding capacity, which enabled the integration of real geographical elements (topography, scale, and extent), urban components (form, fabric, and functions), and demographic data with mobility patterns, offering a flexibility not achievable with conventional ABM tools. To achieve structural validation of the model before its use in geogames, geodata automatic processing was employed, optimising C:S for academic and urban-modelling purposes (Andhika & Anggita, 2022; Juraschek et al., 2017; Olszewski et al., 2020; Piňos et al., 2020). The simulated urban system was calibrated by adjusting population, distances, and urban flows so that the dynamics of the virtual urban fabric mirrored real-world conditions. This process was validated through a comparison with existing urban data, ensuring that the game-based simulation maintained spatial and functional coherence for geoplay before its application in geogames.

Table 1. C:S mods used in the study and their primary functions.

Mod	Functionalities
OpenStreetMap Import	Integrates real-world topography and networks
Ploppable RICO 2.5.6	Enables the placement of specific buildings
Improved Public Transport 2	Manages public transport lines and vehicle assignments
Real Time 2.6	Simulates more realistic citizen schedules and routines
CSL Map View	Exports map imagery and cartographic views
Traffic Volume	Statistics on modal share and traffic routes
More City Statistics	Expands available urban metrics and temporal data
Realistic Population 2	Adjusts demographic probabilities and mobility patterns
TM:PE 11.9.1.0	Provides detailed junction, lane, and traffic controls

4.3. Interconnected Geogames Using the Game-Based Simulation of Concepción

To refine the methodological strategy, we organised it into five interconnected phases that ensure coherence between game-based simulation approaches, their implementation in geogames, and their capacity to support citizen participation and sustainable decision-making in urban planning. This methodological synthesis is presented in Figure 3.

4.3.1. Phase 1: Exploratory Geogame and Game-Based Simulation Validation

Once the C:S scenario was completed, an initial geogame—Which Mode Is Better?—was designed with a purely exploratory focus, aimed at calibrating the game-based simulation and validating its functionality within the SUP framework. Participant selection reflected the study's exploratory scope: Six experts were invited based on their disciplinary backgrounds in architecture, urban sociology, geography, urban mobility, and sustainable planning. This ensured a diverse range of perspectives relevant to AM and participatory urban design. Their expertise provided the basis for calibrating the model of Concepción and framing the initial scenario in relation to local contingencies (Carrasco, 2023).

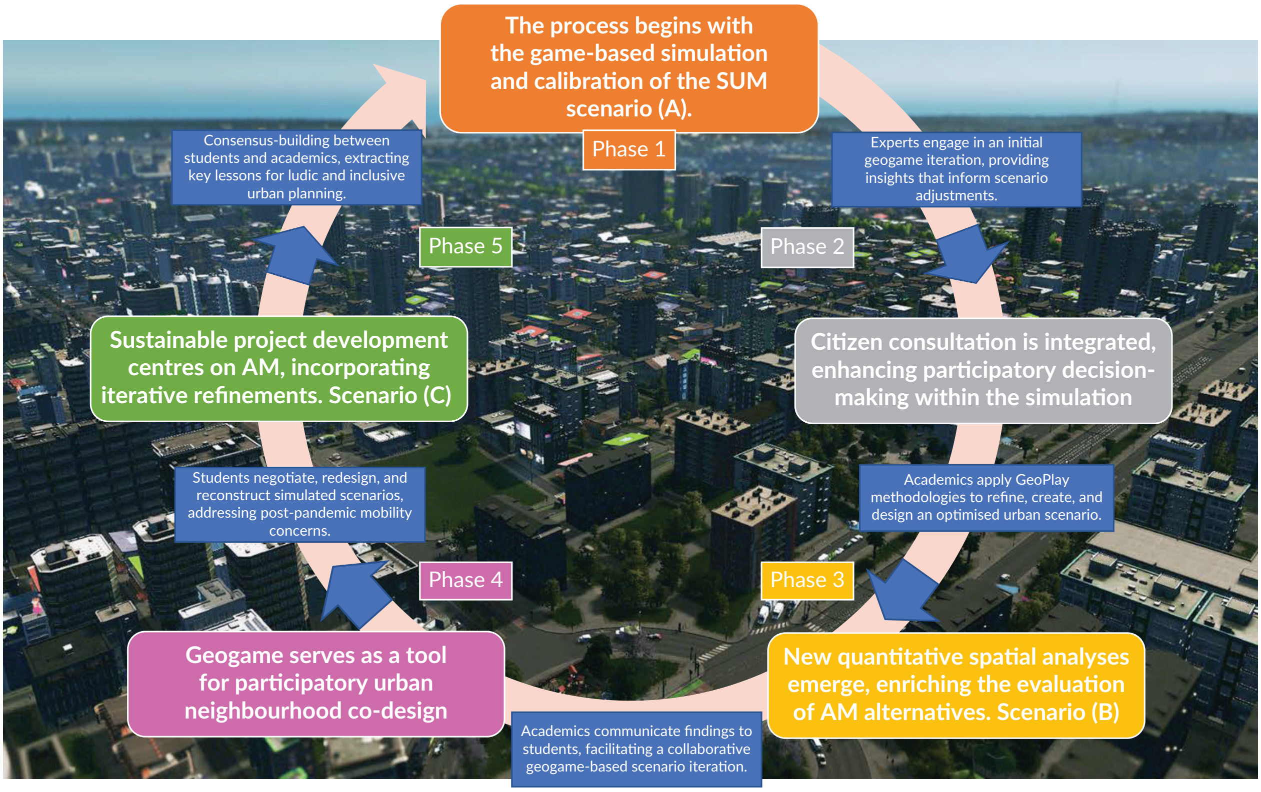

Figure 3. Dual geogame interconnected methodology. The main objective of each phase is highlighted in the blue box.

4.3.2. Phase 2: Incorporating Citizen Perception and Evaluating Impacts

Building on the insights gained from the initial geogame, citizen perception was incorporated by integrating sustainable alternatives proposed to improve AM during the Covid-19 pandemic. These alternatives, collected using social geomarketing techniques in Núñez, Albornoz, Gutiérrez, and Zumelzu (2022) and Núñez Cerda et al. (2024), quantified travel preferences, accessibility perceptions, resident-identified barriers, and satisfaction levels through a stated preference survey. Using these data, the impact of sustainable alternatives on urban agents' AM behaviour was simulated, generating a sustainable scenario in which the neighbourhood subsystem of Collao within the urban model of Concepción was modified through geoplay.

4.3.3. Comparative Strategy Between Two Game-Based Simulated Scenarios

To assess these modal shifts, geoplay was used to create a duplicate of the virtual urban system, iterating a modified version (B) with the declared alternatives alongside the original unmodified version (A). This allowed for a comparative analysis of AM dynamics by measuring differences in urban agents' interactions within each scenario.

4.3.4. Phase 4: Which Scenario Works Best?

A second geogame with partial game-based simulation results was designed to enable the visualisation, exploration, communication, redesign, reconstruction, and negotiation of post-pandemic alternatives. Undergraduate architecture students enrolled in the Urbanism II course (average age 20 years) were selected, as they represent both "informed citizens" and a demographic group typically targeted by participatory geogames (Poplin et al., 2020, 2022). Their involvement was particularly suitable for testing the pedagogical and collaborative potential of the methodology. This sampling choice aligns with exploratory practices in urban living labs, where student-based prototyping is commonly employed to refine participatory tools in controlled environments (Martínez-Bello et al., 2021; Morales et al., 2023). Their familiarity with urban concepts and their age—representative of a key demographic for AM—facilitated a critical yet accessible engagement with the game-based simulation. While not fully generalisable, this sample offered valuable insights into the methodological performance of the geogame framework, serving as a pilot stage before broader application with more diverse stakeholders (Almeida & Deutsch, 2025). Students assessed spatial variations in modal travel preferences and neighbourhood design, ultimately engaging in all phases of the geogame and co-creating a new post-pandemic scenario (C), derived from Scenario B.

4.3.5. Phase 5: Consolidating a Dual and Interconnected Geogame Strategy

The second geogame refined previous insights and consolidated a dual strategy interconnected across different stages of SUP, in line with Poplin et al. (2020). This process led to the co-creation of a sustainable urban design project aimed at improving conditions for satisfactory AM within the study group. To systematically evaluate participants' experiences, a structured survey was implemented, covering seven thematic areas: (a) game-based simulation experience; (b) role and decision-making; (c) learning and critical thinking; (d) collaboration and participation; (e) perceived change and transformative experience; (f) scenario comparison; and (g) overall evaluation. Each thematic block was explicitly linked to one or more phases of the geogame, including the embedded game-based simulation, thereby ensuring that the survey captured the full range of participant interactions across the process.

Responses were collected using a 5-point Likert scale (1 = *strongly disagree*; 5 = *strongly agree*), which enabled the quantification of general perception trends across the group. To complement this, open-ended questions were integrated into each thematic area, inviting participants to elaborate on their perceptions, reflect on specific aspects of the game-based simulation, and propose improvements. The combination of quantitative and qualitative items provided both breadth and depth: Descriptive statistics (frequencies and percentages) offered an overview of patterns in student responses, while thematic coding of open-ended answers added contextual richness and highlighted recurrent illustrative reflections or concerns. This descriptive–interpretive strategy was deemed appropriate for an exploratory pilot, as it allowed findings to inform the assessment of methodological performance without overstating generalisability. The full survey instrument is openly available for consultation: https://forms.gle/yxSBZ9GLVoZ9kCg9A

All phases were conducted in accordance with the ethical guidelines of the University of Bío-Bío. The protocol was formally approved by the University's Research Ethics Committee. Participation was entirely voluntary, informed consent was obtained through an official form, and no personal identifiers or sensitive data were collected, ensuring confidentiality and strict adherence to institutional standards. For reference, all participant quotes used illustratively in the next section of results and discussion are anonymised and identified with sequential codes (e.g., Expert-UM-00 = Urban Mobility experts; Expert-UP-00 = Urban Planning experts; Student-00 = student participants).

5. Results and Discussion

The results are presented sequentially, following the methodological phases. They are structured around the dual and interconnected geogame configuration, emphasising its role within the SUP framework and its potential impact on urban decision-making. This integrated presentation enables an immediate discussion of the findings in relation to the theoretical framework and methodological strategy, thereby reinforcing the contribution of geogames incorporating a game-based simulation as a tool for SUP.

5.1. Game-Based Simulation of Concepción

The initial game-based simulation, serving as the foundation for the dual-geogame framework, was calibrated with real urban flows following Piňos et al. (2020); see Figures 4a and 4b in the current article. To enhance accuracy, we incorporated a rigorous process of spatial, demographic, and subsystem-level validation. Spatially, the CSL Map View mod exported raster maps from C:S to ArcGIS Pro, enabling validation of geographic extent, network lengths, and urban morphology against official cartographic data of Concepción (Figure 4c), as in Olszewski et al. (2020). For example, the Collao neighbourhood has

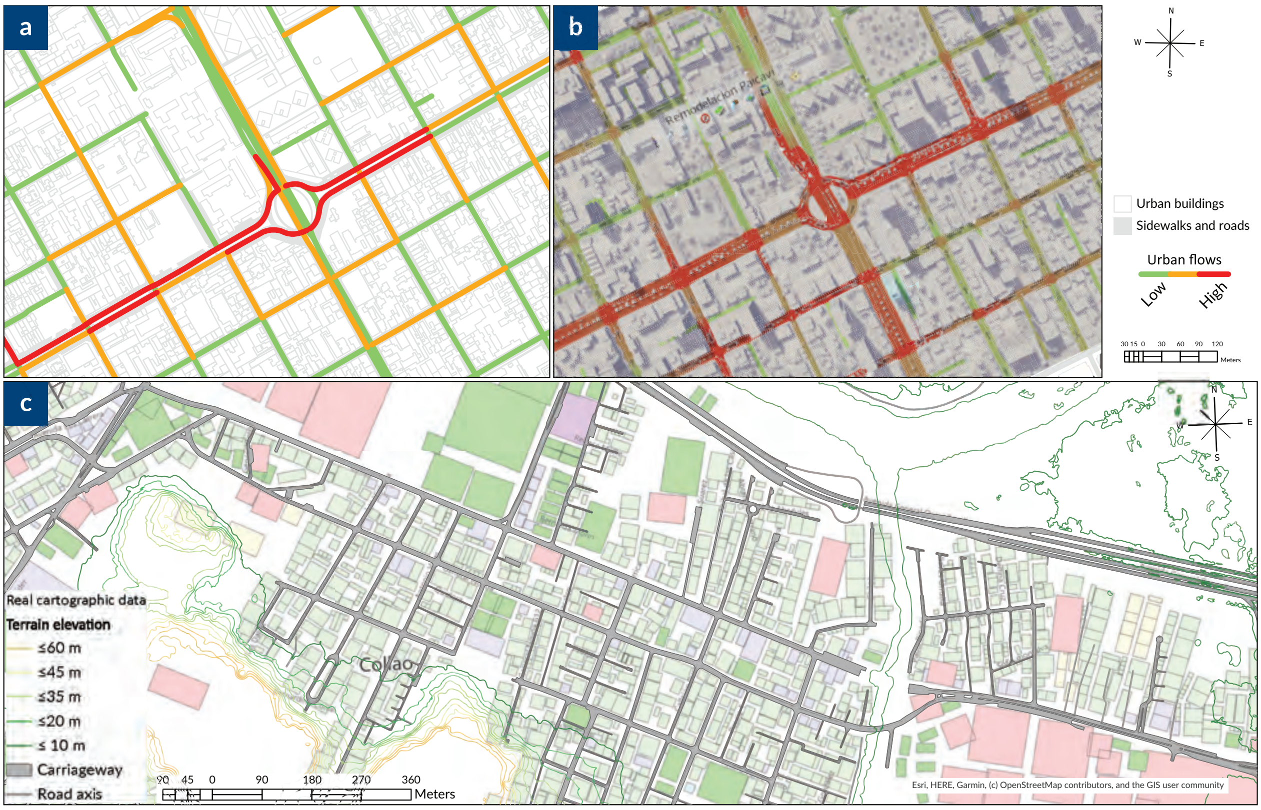

Figure 4. Calibration of Concepción in C:S: (a) observed real-world traffic flows; (b) simulated traffic flows in C:S; (c) real cartography overlaid on a raster base exported from C:S.

approximately 20,412 residents, while the simulated population in C:S was 20,186, indicating close alignment between observed and modelled demographic patterns. This refinement reinforces the value of geoplay, as it enables the adjustment of environmental elements and the co-creation of urban solutions with quantitative data. Overall, the approach strengthens the theoretical foundations of geogames as participatory tools, consistent with the geographical principles of Ahlqvist and Schlieder (2018) and the participatory frameworks discussed by Poplin et al. (2020). Thus, geogames emerge as a bridge between game-based simulations and real urban dynamics, underscoring their applicability in SUP.

5.2. First Calibration Geogame: Which Mode Is Better?

To assess the applicability of Concepción's game-based simulation in C:S within a geogame, we conducted an exploratory phase to validate the urban model and examine its potential as a decision-support tool. Experts in urban planning and mobility explored the city to evaluate geospatial accuracy and functional reliability, consistent with studies that highlight expert validation as essential for digital simulations (Mayer et al., 2005). The main objective was to analyse changes in traffic flow under different transport scenarios, geoplaying within a structured debate on infrastructure (Carrasco, 2023). Game-based simulation has been shown to support scenario-based decision-making in spatial planning (Ahlqvist & Schlieder, 2018; de Andrade et al., 2020). Two scenarios were tested: (a) Base Scenario—no public transport intervention; and (b) Tram Scenario—introduction of a tram network. Using cartographic data and statistical outputs exported from C:S, the tram-based scenario improves overall traffic flow by more than 60% (Figure 5). Experts highlighted the tool's ability to visualise real-time impacts of SUM strategies, reinforcing prior findings on the value of geogames for urban experimentation and participatory planning (Poplin et al., 2020, 2022; Poplin & Vemuri, 2018; Vieira & Coutinho, 2016).

5.2.1. Preliminary Results: Perceptions and Experience

During the calibration geogame, experts emphasised the novelty of the approach and its potential as a realistic geo-urban game-based simulation. They valued the model's capacity to visualise, explore, and analyse urban dynamics through active simulations, consistent with studies distinguishing interactive methods from static modelling tools (Roumpani, 2022; Shi et al., 2025):

> Beyond aesthetics and 3D modelling, this is about playing with consequences through ABM when introducing changes to a system. It's about seeing in real time, "What would happen if...?" (Expert-UP-01, 2024)

Unlike traditional GIS models reliant on static datasets (Heppenstall et al., 2012; Mohammadi & Taylor, 2017), C:S enabled participants to test interventions dynamically, reducing both the cost and risk of real-world experimentation (Shakeri, 2022). This aligns with the theoretical grounding of ABM, where cities are framed as complex self-organising systems, and interactions among agents produce emergent patterns (Bersini, 2012; Vélez, 2019). Experts also acknowledged the value of ABM for participatory planning, as it allows game-based simulation of mobility and accessibility dynamics in bottom-up contexts (Semeraro et al., 2020):

> I've always wanted to know what would happen if we removed private cars from a city or its centre. How would people organise their mobility? (Expert-UM-01, 2024)

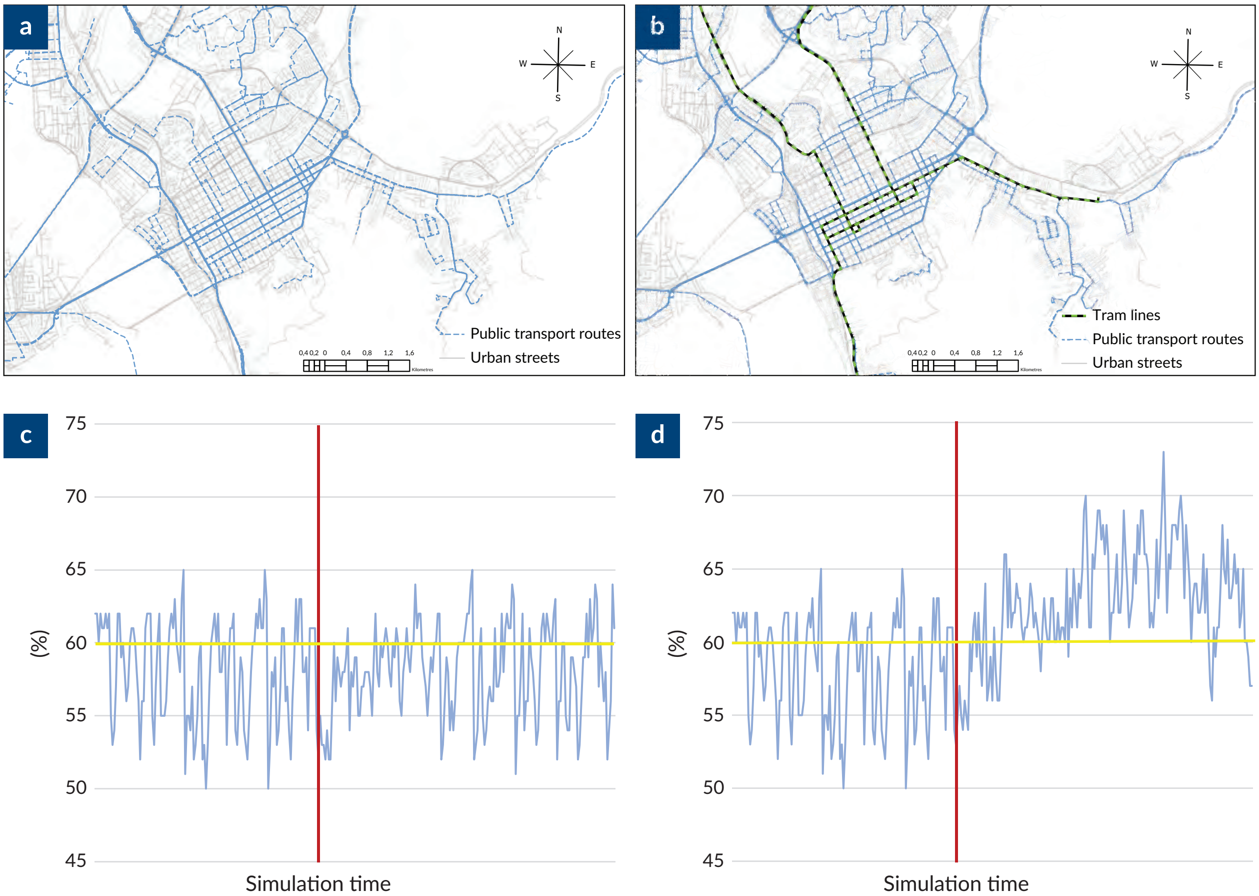

Figure 5. Summary of scenarios and traffic dynamics variations: (a) base scenario; (b) tram scenario; (c) traffic flow efficiency in the base scenario; (d) traffic flow efficiency in the tram scenario. The implemented modifications (red x-axis) improve overall traffic flow by over 60% (yellow y-axis).

This concern aligns with SUP and AM approaches, where game-based simulation in the geogame acts as an experimental laboratory for testing alternative scenarios under expert review (Juraschek et al., 2017; Olszewski et al., 2020; Piňos & Burian, 2022). In this case, the model was used to evaluate the reconfiguration of public space for promoting AM (Haufe et al., 2016; Markvica et al., 2020; Núñez Cerda et al., 2024). Experts highlighted the value of geogames for participatory planning, as they enable both citizens and professionals to experiment with sustainable mobility strategies before real-world implementation. By reducing quantitative uncertainties and exploring systemic traffic impacts, participants proposed the co-creation of an integrated and sustainable transport system (Figure 5):

> The tram used to follow the old cart path along here....Look, let's connect that route to the city centre, maybe by reallocating street space from private vehicles. (Expert-UM-01, 2024)

> Based on its realistic simulations, we could reach decision-making stages with data—not exact, but approximate: from 55% to 65% traffic flow. That would allow us to sit down and discuss changes in real time. (Expert-UP-01, 2024)

Building on these reflections, participants stressed the importance of prioritising citizen perceptions and mobility alternatives as the basis for testing new scenarios. This shift reinforced the bottom-up approach emphasised by Semeraro et al. (2020), where decision-making emerges from citizens towards governance. Within this framework, ABM remains essential for modelling emergent interactions in urban systems (Bersini, 2012; Vélez, 2019):

> Do you have any information on participatory initiatives or citizen consultations regarding perceptions and everyday mobility preferences? (Expert-UM-02, 2024)

Rather than focusing exclusively on mass transit, participants suggested strategies to improve individual travel within the 15-minute city framework (Guzmán et al., 2024). They also highlighted the need to enhance urban elements that support AM and healthy cities, echoing findings on accessibility, well-being, and social sustainability (Herrmann-Lunecke et al., 2020; Núñez, Albornoz, Gutiérrez, & Zumelzu, 2022; Núñez Cerda et al., 2024; Zumelzu et al., 2022, 2024):

> Is it possible to test not only changes in design and infrastructure? Does C:S allow for modifications in public policy and other phenomena? (Expert-UP-02, 2024)

These insights underline the value of expanding decision-making processes to include citizens, ensuring that urban design projects genuinely contribute to SUP. By incorporating perceptions into quantitative game-based simulations, geogames can help reduce uncertainty and evaluate not only spatial interventions but also broader policy measures. This question and these discussions underscore the potential of geogames as playful strategies to capture citizen perceptions and integrate them into game-based urban modelling with policy simulation, thereby fostering more equitable and sustainable solutions aligned with SUP (Poplin et al., 2020). Participants highlighted the importance of expanding scenarios beyond infrastructure to include management and regulatory strategies, bridging theoretical modelling with real urban dynamics (Ruiz-Tagle et al., 2009; Waddell, 2002). In response, a second geogame was designed to incorporate the negotiated outcomes into the Concepción game-based simulation in C:S. Unlike the expert phase, this instance engaged university students from the Collao area—everyday users of AM and urban accessibility— whose feedback offered valuable insights into local perceptions. This new dual-geogame framework thus operates at two levels: (a) structured geoplay with experts to validate urban strategies within the SUM framework, contributing to the observations of Jolly and Budke (2023); and (b) interconnected game-based simulation with citizens-in-training to test participatory redesign processes and support more inclusive governance.

5.3. Second Geogame: Which Scenario Works Best?

The second geogame was implemented with 21 undergraduate architecture students, who engaged both individually and in teams (Figure 6). The activity began with an introduction to the conceptual foundations of geogames and their framework, following the phases outlined by Poplin et al. (2020, 2022). To contextualise the exercise, students reviewed interim results from the first geogame, including the iterative game-based simulation of Scenario B that had been negotiated and proposed by experts. Preliminary results for the Collao scenario indicate an average daytime increase of 44.3% in walking, a 178.7% increase in bicycle use, and a 2.4% positive variation in perceived satisfaction compared with the same scenario without modifications. Finally, at the urban system level, traffic flow efficiency increased by 1.23% (Figure 7). A demonstration video of the simulated city in C:S was then presented, illustrating how such tools can support AM and stimulate students' interest in the application of game-based simulations. After this initial stage, students participated in scheduled geogame sessions with C:S, where they explored the simulated environment and contributed to developing a new sustainable urban scenario (Scenario C) by incorporating their proposals into Scenario B. Upon completion, a survey designed for this study was administered to evaluate their perceptions and the methodological outcomes.

Figure 6. Students interacting with C:S.

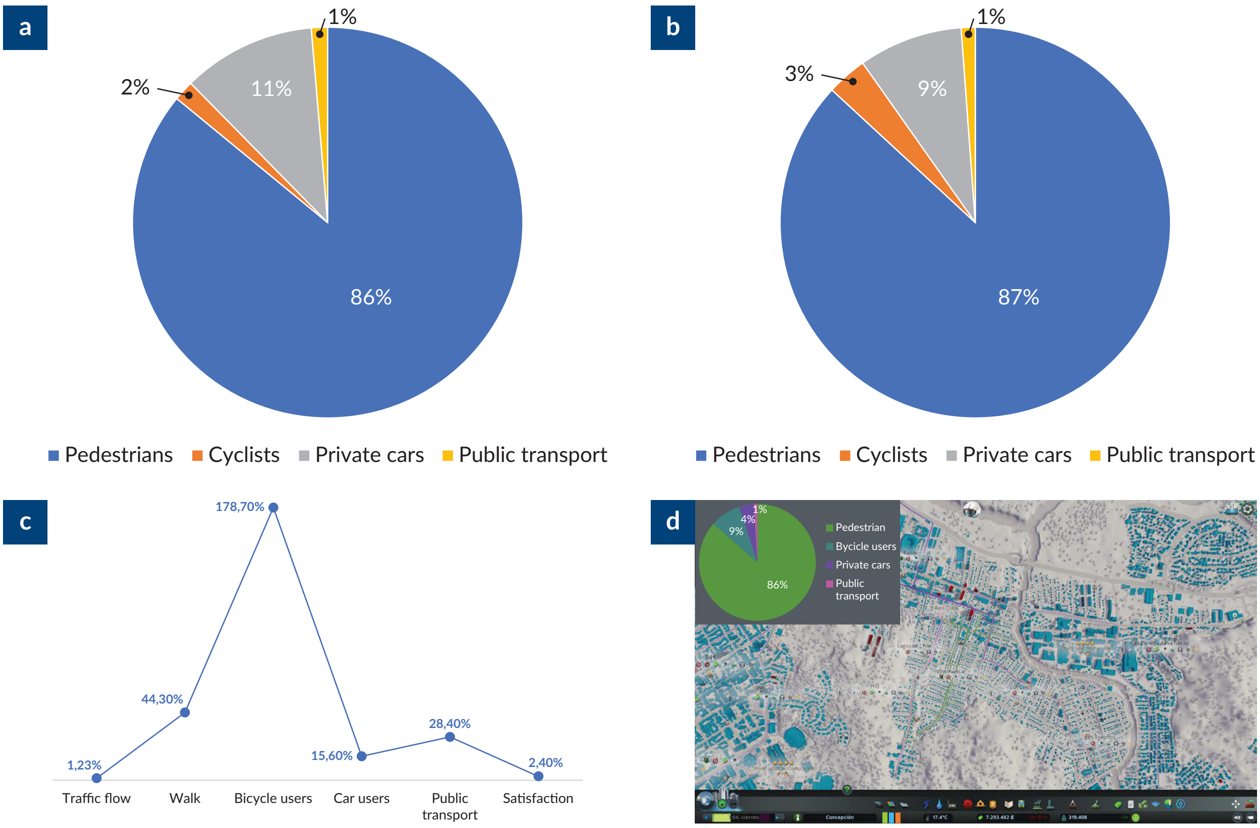

Figure 7. Comparison of Collao scenarios communicated to students: (a) urban system baseline modal split; (b) urban system modal split after expert-proposed modifications; (c) percentage variations for Concepción; (d) Collao in C:S with applied modifications.

5.3.1. Visualisation and Exploration

Students reported that comparing alternative scenarios through the game-based simulation in C:S was both immersive and realistic, with 100% agreeing (28.6%) or strongly agreeing (71.4%) that it effectively reflected real-world urban challenges (Figure 8). All participants also stated that the gameplay dynamic motivated their active involvement and facilitated their understanding of SUP. These findings support Ahlqvist and Schlieder's (2018) argument on the intersection of geographic concepts with play, where realistic game-based simulations play a central role, and align with Crooks et al. (2019) on the potential of ABM-based GIScience. In this sense, geogames and geoplay provide dynamic means of modelling urban systems that interrelate objects, agents, and rules within a playful environment, while remaining grounded in quantitative spatial data. These results validate theoretical propositions and highlight how geogames can communicate participant roles and support decision-making in SUP.

Figure 8. Comparison of game-based simulated scenarios in C:S: (a) base routes and modal split; (b) resulting routes and modal split after simulated variations; (c) geospatial view of the base scenario; (d) geospatial view of the modified scenario with an updated built environment.

5.3.2. Communication and Evaluation

At this stage, students assumed the role of "omnipotent planners," a common feature in academic and game-based simulations, allowing them to freely explore and make decisions in a top-down urban planning context. Most participants (85.7%) reported feeling in full control and demonstrated a clear understanding of the role, while 14.3% expressed doubts, highlighting ethical–moral concerns about the implications of urban decisions—for example, rezoning or expropriating residential areas to create public spaces. These reflections were reinforced in the evaluation phase, where 85.7% agreed that the geogame helped them critically assess the impacts of planning choices and understand their consequences within the game-based simulation. Such findings resonate with Bereitschaft's (2015) critique of urban video game simulations, highlighting progress in fostering participatory engagement. However, a minority remained unconvinced of these benefits. This underscores the need to refine playful strategies that broaden inclusion, in line with Raghothama et al.'s work (2022) on openness and complexity in planning environments. Building on this stage, students were then assigned collaborative roles that incorporated other stakeholders' perspectives, leading them to redesign the Collao neighbourhood with a focus on AM, aligned with bottom-up approaches (Semeraro et al., 2020).

5.3.3. Redesign and Collaborative Negotiation

Students compared the original scenario—lacking community-informed alternatives—with the pandemic-era scenario (B) that incorporated proposals from Collao residents. While 28.6% considered the latter effective, 71.4% argued for a redesign, emphasising the dynamic and evolving nature of cities. Their reflections motivated the creation of a post-pandemic scenario (C), aimed at strengthening AM through new interventions. This process supports the use of perception-based methods for modal shift interventions (Haufe et al., 2016; Markvica et al., 2020) and aligns with walkability improvements suggested by Herrmann-Lunecke et al. (2020) and Zumelzu et al. (2022, 2024), which have been linked to greater satisfaction with urban environments (Núñez Cerda et al., 2024):

> Collaboration enabled us to develop a better scenario by combining both perspectives. (Student-01, 2025)

> Our city is constantly changing, so it wouldn't be feasible to rely solely on a pandemic-based scenario. (Student-03, 2025)

The collaborative dimension of the geogame was also evident: 85.7% of students agreed that the dynamic encouraged teamwork, while 71.4% highlighted the value of incorporating others' perspectives. Even participants working individually benefited from facilitator guidance, confirming the importance of structured support in participatory simulations (de Andrade et al., 2020; Poplin et al., 2020, 2022). Across all groups, the geogame fostered a sense of belonging to a learning community, reinforcing findings from earlier implementations. These results contribute to the debate on the role of playful elements in gamified processes, especially in decision-making and role-playing (Hammady & Arnab, 2022; Krath et al., 2021; Robinson et al., 2021; Senior et al., 2023). Ultimately, Scenario C illustrates how a playful quantitative game-based simulation—embedded within an interconnected geogame framework grounded in real geographic elements—can facilitate consensus-building and spontaneous learning through the development of an urban design project (Figure 9).

5.3.4. Consensus and Learning

The second geogame revealed strong consensus-building dynamics and meaningful learning outcomes. A total of 71.4% of participants agreed that the ludic game-based simulation enhanced their understanding of urban sustainability concepts, supporting Senior et al.'s (2023) findings on playful learning. All students

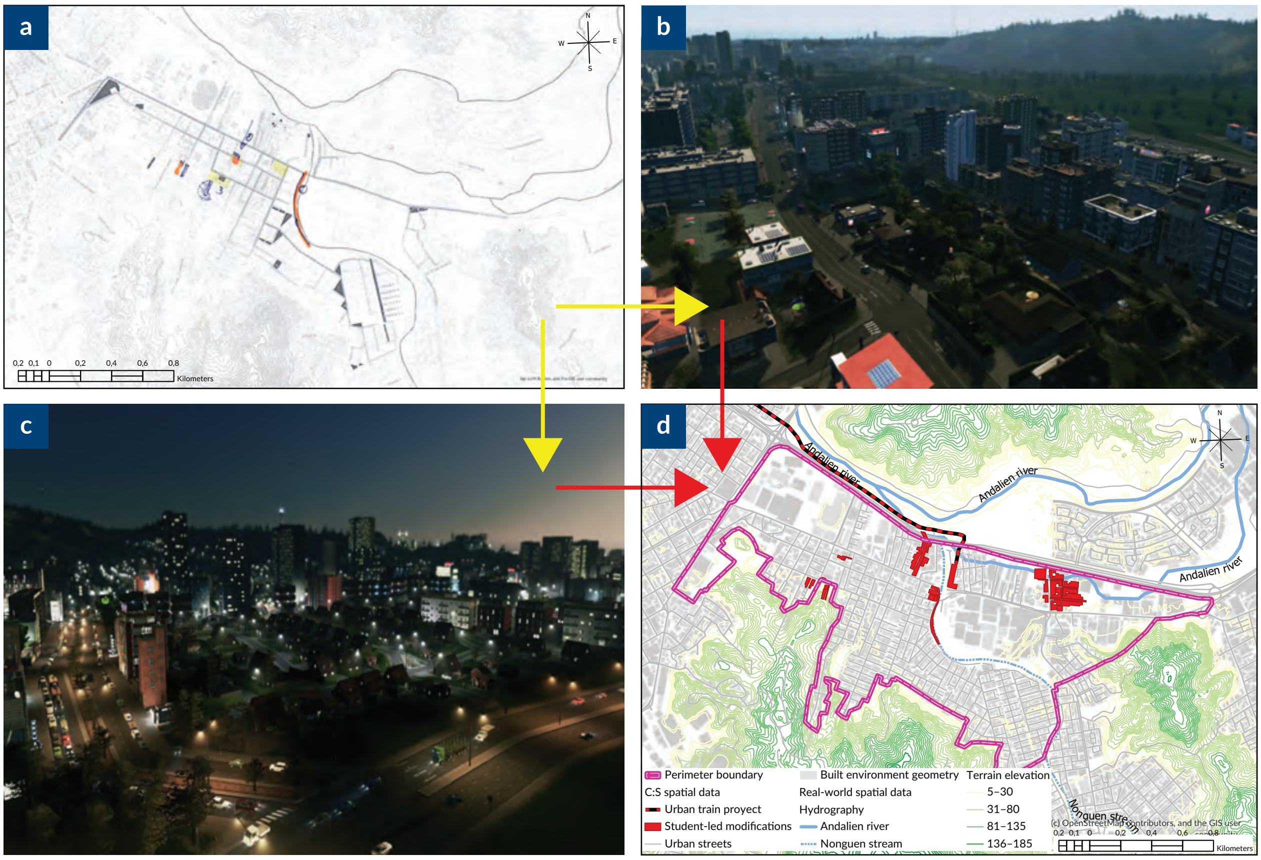

Figure 9. Sustainable urban design project process of Scenario C: (a) student sketch of proposed interventions; (b–c) game-based simulation of these interventions in C:S; (d) final cartographic outputs exported to ArcGIS Pro. Yellow arrows indicate the transfer of design alternatives into C:S; red arrows indicate their georeferenced mapping in the Collao neighbourhood.

also recognised that the quantitative dimension of C:S facilitated critical reflection on competing urban interests and the complexity of planning processes, thus contributing to the development of a civic perspective on urban problems. Students proposed diverse interventions that moved beyond vehicle-centred planning (Núñez Cerda et al., 2024; Zumelzu et al., 2024), including multimodal transport, public space improvements, and proximity-based housing:

> My teammate and I proposed implementing a Biotren line to reduce congestion, along with enhancements to cycle lanes in Collao–Novoa, better lighting, and improved pedestrian walkways. (Student-02, 2025)

> I decided to design residential buildings near key destinations—such as the university—to encourage mobility through proximity, particularly for students. (Student-04, 2025)

Through these exchanges, students reached consensus both among peers and with facilitators, reflecting the iterative negotiation processes of SUP. The immediacy of testing proposals within the simulation fostered what we term a "metaconsensus," emerging from the recurring question: "What would happen if we implemented this?". Participants also highlighted the intuitive and realistic nature of C:S, underscoring its role in facilitating agreement and future-oriented planning:

> Intuitive, and a very useful tool for learning all the things that need to be considered before making any changes within a city. (Student-10, 2025)

> I learnt that it is important to share my point of view and personal experiences to contribute to urban improvement. (Student-05, 2025)

These reflections reinforce Ahlqvist and Schlieder's (2018) notion of "georealistic" simulations, illustrating how game-based simulations embedded in geogames can enhance both individual learning and collective decision-making in urban contexts. Building on this idea, geogames emphasise playful interaction, negotiation, and co-creation, articulated here through a novel geogame-based simulation approach. Unlike other digital participatory tools such as digital twins or VR games, which focus mainly on representation, geogames add a playful and collaborative layer that strengthens inclusive and participatory decision-making, fully aligning with the principles of SUP (Poplin et al., 2020). These insights provide the foundation for the key contributions of the dual and interconnected geogame framework.

5.4. Key Contributions of the Dual Interconnected Geogame

Responding to the research question and objective, our results suggest that the dual and interconnected geogame—built on distinct game-based simulation strategies—provides a feasible and innovative method within SUP for fostering socially sustainable active mobility. By incorporating a game-based simulation tool, this approach reinforces the role of geogames as instruments for co-creating urban strategies through quantitative urban data modelling. By enabling participatory decision-making in complex urban systems, it allows diverse actors to negotiate shared interests and generate context-sensitive solutions. Overall, the findings point to progress towards the democratisation of complex urban planning processes, consistent with Rodríguez (2018). The key contributions of each iteration are summarised in Table 2.

Table 2. Contributions of each interconnected geogame iteration.

Aspect	Scenario A	Scenario B	Scenario C
Participants	Planning and mobility experts	Facilitators	Architecture students
Objective	Validate game-based simulation	Test citizen-informed AM alternatives	Co-create post-pandemic design improvements
Method	SUM scenario testing	Geoplay with social geomarketing data	Immersive game-based simulation and scenario redesign
Role Assumed	Initial omniscient planner (top-down urban planning)	Scenario B tester	Collaborative designer (bottom-up urban planning)
Outcome	Game-based simulation validated for bottom-up planning	Improved modal shift and spatial accessibility	Scenario C achieved metaconsensus through participatory co-creation
SUP Contribution	Introduced C:S for expert-based analysis	Integration of bottom-up data	Reinforced geogames for systemic, playful, and inclusive urban design

6. Final conclusions

This study suggests the feasibility of integrating quantitative urban data into participatory geogames through game-based simulation, in line with our initial hypothesis and objective. The dual and interconnected geogame methodology appears to enable both experts and students to interact with real spatial data in C:S; experts contributed to the calibration and validation of a sustainable scenario (B), while students co-designed an enhanced version (C) informed by citizen preferences. The findings point to the potential of geogames as decision-support tools that may foster metaconsensus, strengthen civic engagement, and promote systemic and inclusive urban co-creation through the guiding question "What if?" By linking playful design with AM promotion, geogames may be positioned as methodological innovations for advancing SUP and contributing to socially sustainable active mobility. The second geogame, in particular, illustrates how game-based simulation might empower citizens as critical agents in addressing urban challenges while supporting learning and collaboration. Overall, the research indicates that geogames may act as a bridge between quantitative game-based simulation and bottom-up planning, as suggested by Cartes-Siade et al. (2024, p. 122), and provides additional evidence of their potential to generate metaconsensus and democratise decision-making in complex urban systems, especially in resource-constrained Global South contexts. As such, this study should be read as a proof of concept, suggesting a transferable methodological pathway for medium-sized cities in similar contexts.

Nonetheless, the scalability of the dual-geogame methodology may remain constrained by the need for tailored facilitation, technical configurations, and participant training, which could limit its broader application in low-capacity institutional settings. Although the game-based simulations integrated real demographic and spatial data, they did not yet incorporate live or time-sensitive datasets that might improve responsiveness and decision-making accuracy. Participant involvement—while rich in qualitative feedback—was limited to small-scale pilots with experts and undergraduate architecture students. The latter offered valuable insights into the methodological performance of the framework, but represent a relatively homogeneous group in terms of age, background, and exposure to urban concepts, which may introduce biases and limit generalisability. Their dual role as both "informed citizens" and future professionals could further influence perceptions and negotiation processes. Still, positioning students as an exploratory sample aligns with living lab practices and student-based prototyping, where early testing in controlled environments is used to refine participatory tools before engaging broader and more diverse stakeholders, in line with the quintuple helix model proposed by Almeida and Deutsch (2025), for example. Ethical safeguards—including institutional approval, informed consent, and data confidentiality—were followed, yet gamified participation also raises questions of inclusion, as factors such as age, digital literacy, or gaming experience may shape engagement. Future research should therefore broaden stakeholder diversity and explore additional safeguards to enhance inclusivity, strengthening the robustness and representativeness of participatory planning outcomes.

In this light, geogames may emerge as disruptive methodologies that challenge conventional planning approaches (Hudson-Smith & Shakeri, 2022; Poplin et al., 2022), opening new avenues for more democratic, playful, and data-informed urban governance. Future research could explore the integration of real-time data, adaptive AI systems, and the involvement of more diverse stakeholder groups across all phases of SUP, and further consolidate the role of interconnected geogame-based simulation as agile and participatory tools. Future research could also contrast geogame-based simulations with other digital participatory approaches to evaluate their relative effectiveness in fostering socially sustainable active mobility and other urban transformations—ultimately positioning geogames as part of The Future's Language of Urban and Regional Planning.

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Conflict of Interests

The authors declare no conflict of interests.

Data Availability

The full survey instrument is openly available for consultation: https://forms.gle/yxSBZ9GLVoZ9kCg9A

Supplementary Material

Supplementary material for this article is available online in the format provided by the authors (unedited).

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