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DIGITAL TOOLS AND THE FOUR-C MODEL IN URBAN GREENERY PLANNING: HOW ARTIFICIAL INTELLIGENCE AND GEOGRAPHIC INFORMATION SYSTEMS SHAPE CREATIVITY, COMMUNICATION, AND AGENCY

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Abstract. This article examines how Artificial Intelligence (AI) and Geographic Information Systems (GIS) mediate creativity, sustainability communication, and agency in participatory urban planning focused on greenery integration. Employing a comparative secondary analysis and a most-different-systems design (MDSD), we interpret two contrasting initiatives: an AI-assisted intergenerational workshop in Betania, Panama, and a GIS-enabled citizen science project in Sankt Augustin, Germany. A four-layer analytic pipeline guided the study, combining structured extraction, thematic synthesis, a scoring rubric, and cross-case comparison. The results show that AI facilitated participants' comprehension and creative engagement with complex spatial information through real-time visualization, accelerated divergent ideation, and strengthened intergenerational dialogue, resulting in more than twenty design proposals and measurable increases in inclusion and motivation. GIS, by contrast, elicited distributed evidence through crowdmapping and workshops, converging lay observations into policy-relevant insights and sustaining participation over a longer timeframe. Cross-case synthesis revealed inclusive, digitally mediated participation as the common explanatory factor behind enhanced collaboration and creativity. The study contributes theoretically by connecting Csikszentmihalyi's systems view and the Four C model to digital participation. It proposes a hybrid framework that combines AI's generative speed with GIS's spatial grounding, linking visionary co-design to evidence-based co-production. This approach advances both the theoretical understanding of digitally mediated creativity and the practical guidance available to stakeholders pursuing more inclusive and resilient participatory processes.

Keywords: artificial intelligence, geographic information systems, participatory urban planning, creativity, sustainability communication.

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1. Introduction

The integration of AI and GIS is transforming urban planning through enhanced innovation, spatial analysis, and participatory design. GIS supports inclusive decision-making with visualization and stakeholder engagement, while AI contributes multimodal outputs and scenario development for green space planning, environmental assessments, and climate-responsive analysis (Cudzik & Nessel, 2024; Salimi et al., 2025).

Beyond technical efficiency, AI and GIS support participatory planning by enabling diverse stakeholders to co-create solutions and reshape sustainability communication (Berigüete et al., 2024). Sustainability communication, defined as the exchange of knowledge, visions, and values that foster collective agency toward sustainable futures, is essential for inclusive urban development (Bridges & Guo, 2024). However, research has not sufficiently examined

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how AI and GIS mediate creativity and communication or redistribute agency among participants (Schreiber, 2024).

Grounded in the Systems Model of Creativity and the Four C Model of Creativity, this study asks: How can AI and GIS tools enhance creativity in participatory urban planning while mediating sustainability communication and reshaping agency?

The research pursues three objectives:

1. Develop a lens for evaluating digital participatory tools that shifts focus from efficiency toward creativity and inclusivity.
2. Examine AI and GIS in practice through two contrasting case studies of digitally enabled participation.
3. Propose a conceptual framework showing how digital tools foster sustainability communication and creativity in mutually reinforcing ways.

The novelty lies in reinterpreting existing cases through the integrated perspectives of creativity theory, agency, and sustainability communication. Using a most-different-systems logic, the study identifies tool-specific strengths and limitations and proposes a framework showing how AI and GIS function as complementary paradigms of digital participation.

2. Digital participation and collaborative practices: existing frameworks

2.1. Sustainability communication and collaboration in urban planning

Sustainability communication underpins participatory planning by making spatial information accessible, building trust, and enabling co-creation (Li & Guo, 2024). Agency, the capacity to influence decisions, is mediated by digital instruments, which both empower and constrain actors in different ways (Toukola & Ahola, 2022). When communication and agency are interconnected, visualization technologies expand transparency and participation (Urbanowicz & Nyka, 2016). Viewing technology as a mediator highlight embedding sustainability communication in digital planning processes (Slingerland et al., 2024), operationalized through GIS, crowdsourcing, and generative AI.

2.2. Operationalizing co-creation in the digital environment

Three categories of digital technologies illustrate how co-creation is advancing in urban planning: GIS, crowdsourcing platforms, and generative AI. GIS inform decisions on air quality, hydrology, and food security, while narrative techniques broaden accessibility (Miles et al., 2023). Crowdsourcing integrates community insights, enhances civic engagement, and supports participatory accountability (Haltofová, 2018). Generative AI produces multimodal outputs for human-AI collaboration and participatory design (Cudzik et al., 2024), with platforms such as DALL·E, Midjourney, and Firefly enabling rapid prototyping of alternative urban futures (Fang et al., 2025). Collectively, these tools offer analytical grounding and imaginative exploration.

3. Methods

3.1. Methodological approach

The comparative case study approach is well suited for examining complex sociotechnical systems where digital technologies, planning practices, and community dynamics intersect (Wu & Ma, 2023). It enables both theory generation and practical recommendations, situating digital participation within broader debates on urban transformation. Its relevance is demonstrated by studies on digital infrastructure (Marín et al., 2020) and heterogeneous urban change (Schteingart & Sierra, 2024).

This study applies a theory-driven small-N design using MDSD logic (Przeworski & Teune, 1970). MDSD selects sharply dissimilar cases that share a common outcome to infer the minimum explanatory factor, a logic rooted in Mill's Method of Agreement and widely discussed in comparative methodology (Seawright & Gerring, 2008).

We fixed the outcome as "enhanced participation and collaboration in urban green-space planning" and selected two maximally contrasting modalities. A four-layer analytic pipeline, consisting of structured extraction, deductive thematic synthesis, auditable scoring, and cross-case synthesis, was then applied to identify the smallest common explanatory factor across both cases.

Layer 1: Structured extraction. For each case, key elements, including participants, facilitation, digital toolchain, instruments, and outputs, were systematically extracted using a structured comparison schedule (George & Bennett, 2005), providing a baseline for like-for-like analysis.

Layer 2: Thematic synthesis involved reinterpreting qualitative and quantitative findings across cases, integrating diverse forms of evidence while preserving contextual nuance (Slingerland et al., 2024). A deductive framework based on predefined themes encompassed creativity, participation, intergenerational collaboration, spatial awareness, digital agency, outputs, and limitations (see Table 1). These dimensions align with insights from participatory planning literature (Malpass et al., 2023). To ensure transparency, codes were linked to excerpts and cross-checked collaboratively.

Table 1. Themes and their operationalization through indicators (source: authors)

Theme	Indicators
Creativity	Idea novelty and usefulness; diversity of solutions; balance between exploration and convergence; presence of reflective iteration; artifacts accepted by peers or officials.
Collaborative creativity	Diversity of group proposals; intergenerational negotiation; co-authored outputs; shared problem framing.
Individual creativity	Increased motivation and confidence; standout individual ideas; pre-post perception change.
Participation and inclusion	Pre-post inclusion and motivation (Betania); participation breadth and sustained engagement (Sankt Augustin).
Intergenerational collaboration	Mixed-age groups; testimonials; evidence of mutual learning.
Spatial awareness and problem framing	GIS categories ("too hot", "shade and quiet"); AI before-after visualizations and diagnostic photos.
Agency and mediation by digital tools	AI-supported dialogue and idea generation; GIS-enabled stakeholder dialogue and policy input.

End of Table 1

Theme	Indicators
Outputs and implementation pathways	Betania proposals; Sankt Augustin mapped categories and stakeholder meetings.
Limitations and biases	Digital literacy and self-selection (Sankt Augustin); short workshops and local context limits (Betania).

Layer 3: Creativity and participation scoring. To ensure transparent and auditable judgments, a scoring layer was added, adapted from consensual assessment and the Four-C model of creativity (Kaufman & Beghetto, 2009). Individual creativity was assessed by novelty, appropriateness, and confidence; collaborative creativity by negotiation, co-authorship, and shared outputs. Participation breadth, inclusion change, and sustained engagement were scored using counts, composition, pre/post surveys, and evidence of iterative activities or administrator dialogues. The criteria are summarized in Table 2, which stabilizes qualitative judgments and enables systematic comparison across cases.

Table 2. Digital participatory planning evaluation rubric (source: authors)

Dimension	Score 0-1	Score 2-3	Score 4	Score 5
Creativity - Collaborative	No group co-creation or joint decisions	Some co-creation; limited integration	Clear co-creation with shared outputs	Strong, repeated co-creation with multiple outputs
Creativity - Individual	Few contributions; low confidence	Some ideas; partial confidence gains	Distinct ideas; confidence increases	Strong originality with clear confidence and recognition
Participation breadth	Very small or unbalanced sample	Moderate size; some groups missing	Large or mixed groups with inclusion efforts	Very large, balanced groups with documented inclusion
Inclusion change (pre-post)	No data or negative change	Qualitative signs; limited measures	Measured positive change, moderate samples	Substantial change; large samples, multiple items
Sustained engagement	One-off activity, no follow-up	Follow-up planned; limited iteration	Documented iteration (meetings/ workshops)	Longitudinal cycles with validation by administrators and residents

Layer 4: Comparative synthesis. A structured focused comparison ensured transparency and systematic cross-case cumulation, enabling theory building from a small-N design (Douglas et al., 2020). Cross-case synthesis considered quantitative metrics such as participation rates, idea volume, spatial coverage, and engagement; qualitative insights including narrative coherence, thematic diversity, and perceived influence; and tool-specific affordances differentiating AI-assisted and GIS-enabled approaches to urban greenery planning.

3.2. Case study selection

We selected two cases to maximize variation while holding constant the outcome of participatory planning for greener public spaces. Case 1, an AI-assisted workshop in Betania, Panama (Global South), used generative visualizations to scaffold intergenerational ideation (Chemier & Hotsko, 2024). Case 2, an asynchronous web GIS process in Sankt Augustin,

Germany (Global North), employed QGIS Web Client to crowd-map lived experiences and co-prioritize interventions (Klement et al., 2025). The cases differ by region, income, modality (synchronous vs. distributed), technology (AI vs. GIS), and pathway (short design burst vs. extended evidence gathering). Both are well documented and provide auditable material for comparative analysis, enabling an MDSD inference about the common explanatory factor behind enhanced collaborative creativity and participation.

3.3. Participant demographics

Case Study 1: AI-Assisted Workshop. In Betania, university students used UrbanistAI to generate design proposals, while seniors contributed historical and experiential insights, enriching contextual knowledge (Chemier & Hotsko, 2024).

Case Study 2: GIS-Enabled Crowdsourcing. In Sankt Augustin, students acted as citizen researchers, seniors raised practical concerns, and city officials engaged in dialogues shaped by crowdsourced data (Klement et al., 2025).

4. Case studies characteristics

4.1. Case Study 1: UrbanistAI-assisted participatory workshop

The UNDP and Technological University of Panama held an intergenerational urban design workshop in Betania on May 28-29, 2024 (Chemier & Hotsko, 2024). The event tested how generative AI could support social cohesion and participatory planning, engaging 190 participants (165 students, 25 older adults). Groups analyzed public spaces through photography and used UrbanistAI for real-time visualization. Pre-surveys revealed low involvement, limited intergenerational exchange, and skepticism toward AI, with many reporting little motivation for future projects (see Figure 1).

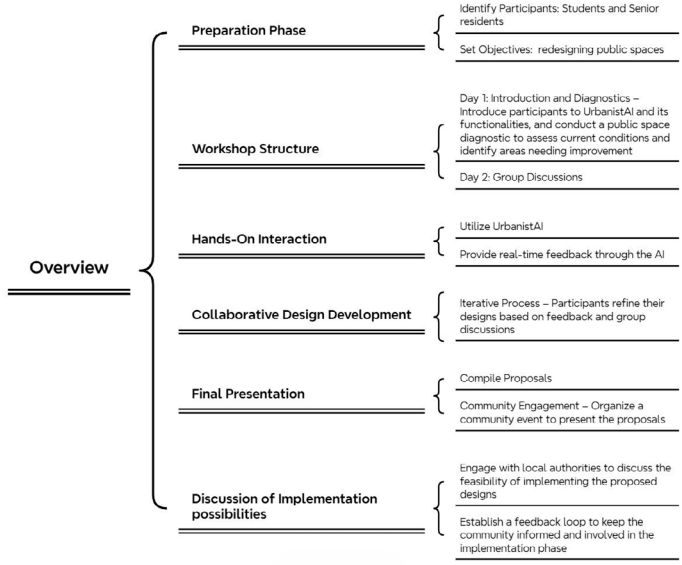


Figure 1. Methodology of AI-assisted intergenerational urban design workshop, Betania, Panama (source: authors)

4.2. Case study 2: Crowdsourcing green interventions via GIS

This study examined how digital tools and crowdmapping connect planning metrics with citizen perceptions by enabling residents to assess and shape more green and resilient urban environments (Klement et al., 2025). In Sankt Augustin, Germany, a decentralized city with limited green space and air pollution above WHO standards, the project was led by H-BRS and the Bonn Science Shop with support from Ruhr University Bochum. Citizens evaluated public spaces through an online GIS tool, documenting experiences, identifying deficiencies, and suggesting improvements. Outreach and self-selection recruited participants, with targeted strategies for underrepresented groups such as older adults with limited digital literacy. Training sessions and walking tours fostered familiarity among participants, while the platform used QGIS Web Client 2 to ensure accessible interaction with spatial data (see Figure 2).

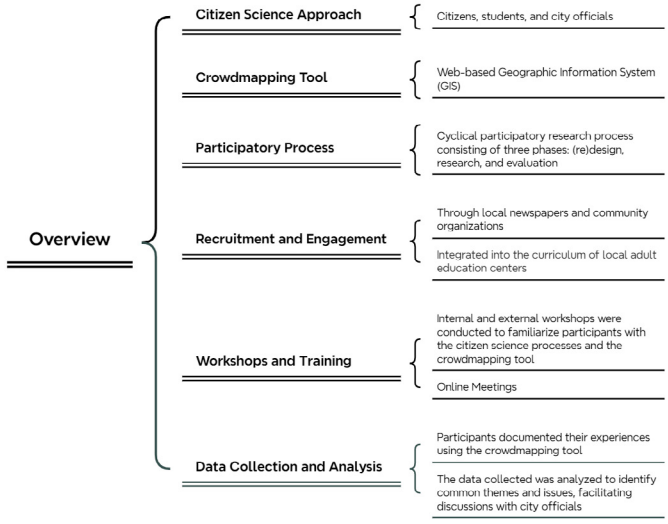


Figure 2. Methodology of GIS-based participatory crowdmapping in Sankt Augustin, Germany (source: authors)

5. Results

Results are presented according to the four analytic layers described in the methodology:

5.1. Descriptive extraction – case studies summaries

- Case Study 1: AI-Assisted Urban Planning Workshops

Intergenerational sessions in Betania produced 20 design proposals on parks, pedestrian safety, and community centers. Post-surveys of 137 participants showed higher inclusion, motivation, and willingness to join future projects, with nearly 90 percent recognising the value of AI-enhanced collaboration. Older adults contributed local knowledge, younger participants offered innovations, and real-time visualizations bridged perspectives into actionable proposals (Chemier & Hotsko, 2024).

- Case Study 2: GIS-Enabled Crowdmapping Initiative

In Sankt Augustin, students and seniors mapped community concerns, highlighting accessibility, heat, and limited green space (Klement et al., 2025). Photos and spatial data identified critical pedestrian zones, but long-term impact was constrained by funding and bureaucratic barriers.

5.2. Thematic synthesis: findings

Findings, structured around predefined themes (see Table 3), indicate that AI workshops in Betania facilitated rapid visualization, structured collaboration, and intergenerational confidence, producing 20+ proposals. GIS crowdmapping in Sankt Augustin fostered gradual creativity through narratives and walks, broadened access despite digital divides, and generated a geospatial evidence base. AI emphasized speed and immediate options, while GIS provided inclusivity and spatial grounding but required longer engagement.

Table 3. Comparison matrix (source: authors)

Dimension	Betania - AI-assisted workshop	Sankt Augustin - GIS-enabled crowdmapping
Creativity	Rapid ideation with instant visualizations; multiple redesigns; higher confidence when ideas rendered.	Gradual idea generation via entries and validation; collective synthesis yields grounded solutions.
Collaborative creativity	Mixed-age groups co-create proposals; visual feedback aids negotiation.	City walks and workshops foster joint prioritization with administrators.
Individual creativity	Original ideas visualized immediately, reinforcing agency and confidence.	Distinct geotagged observations later combined.
Participation and inclusion	Pre n = 151, post n = 137 show increased inclusion and motivation among 190 participants.	Broad participation; uneven access addressed through training and outreach.
Spatial awareness and problem framing	Before/after visualizations crystallize site interventions.	Taxonomy captures heat, shade, dryness, accessibility as georeferenced evidence.
Agency and mediation by digital tools	AI turns ideas into visible options, simplifying complex concepts.	Web GIS legitimizes citizen observations for policy dialogue through structured categories and workshops.
Outputs and implementation	20+ proposals prepared for municipal dialogue.	Shared evidence base supports iterative workshops with administration.
Limitations and biases	Short time horizon; localization needs of AI images.	Digital divide, self-selection, seasonal bias, pandemic constraints.

5.3. Scoring outcomes

The framework assessed collaborative and individual creativity, participation breadth, inclusion change, and sustained engagement (see Table 4). The Betania workshop scored highest in collaborative creativity (5) and inclusion change (5), reflecting strong short-term gains

in intergenerational cooperation. The Sankt Augustin initiative achieved the top score in sustained engagement (5), consistent with its extended, iterative structure. Indices were calculated as arithmetic means: creativity index = (individual + collaborative creativity)/2; participation and inclusion index = (breadth + inclusion change + sustained engagement)/3.

Table 4. Comparative indices of creativity, participation, and inclusion in Betania and Sankt Augustin (source: authors)

Case	Collaborative Creativity	Individual Creativity	Participation breadth	Inclusion change (pre-post)	Sustained engagement	Creativity Index	Participation and Inclusion Index
Betania	5	4	5	5	2	4.5	4
Sankt Augustin	4	4	4	2	5	4	3.66

5.4. Cross-case comparative synthesis

AI and GIS offer diverse affordances (see Figure 3): AI enables structured, rapid co-design; GIS supports inclusive, sustained crowdmapping.

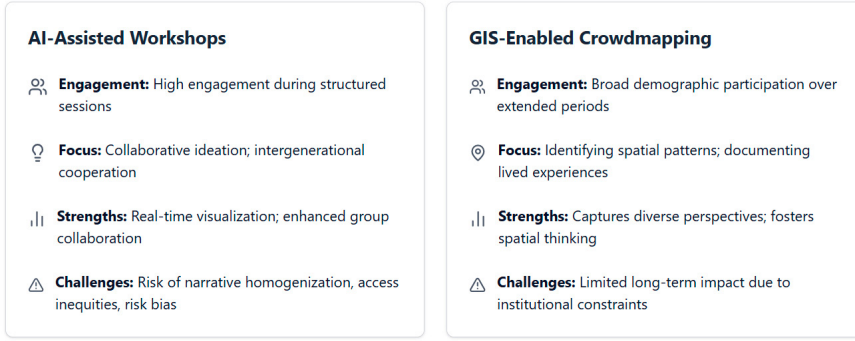


Figure 3. Contrasting participation: strengths and challenges (source: authors)

Using a MDSD, two distinct settings achieved the same outcome: stronger participation and co-creative outputs. The shared factor was an inclusive, digitally mediated setup that expanded contributors beyond experts and structured input for decisions. In Betania, mixed-age co-design with generative AI enabled rapid proposals, while in Sankt Augustin, web GIS and walks validated lay observations as policy evidence. Broad inclusion and transparent mediation consistently explained the common outcome.

6. Discussion

The findings show AI and GIS tools as distinct yet complementary paradigms of digital participation, each fostering creativity differently. AI workshops in Betania produced multiple design solutions and strengthened intergenerational dialogue through real-time visualization, promoting divergent creativity and imaginative exploration (Fang et al., 2025). These dynamics

align with flow (Csikszentmihalyi, 1996) and the Four C model (Kaufman & Beghetto, 2009), activating mini-c and Pro-c creativity.

By contrast, GIS crowdmapping in Sankt Augustin supported convergent creativity, synthesizing observations into shared categories that guided collective decisions. This reflects spatial cognition and place-based understanding (Holloway & Mengersen, 2018), illustrating little-c problem solving and Pro-c creativity when spatial insights informed longer-term planning.

In the AI case, Pro-c emerged as proposals met professional standards, though uptake remained prospective. In the GIS case, Pro-c was evident as resident evidence was validated and introduced into policy dialogues (see Table 5). Together, these dynamics show AI and GIS as mutually enriching tools advancing different modes and dimensions of creativity (see Figure 4).

Table 5. Application of the Four-C model of creativity (source: authors)

Case	mini-c (personal)	little-c (everyday)	pro-c (professional)	big-C (eminent)
Betania - AI	Present	Present	Emerging	Not expected
Sankt Augustin - GIS	Present	Present	Present	Not expected

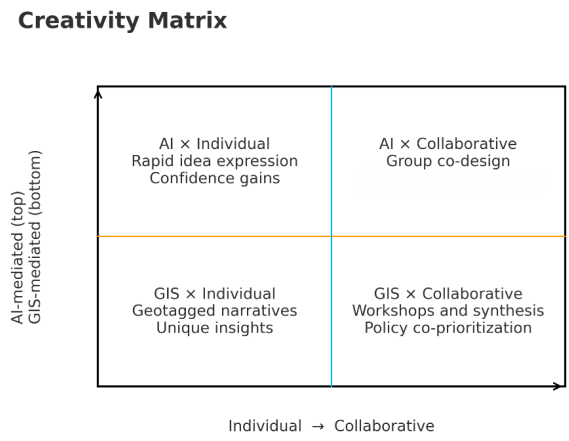


Figure 4. AI- and GIS-mediated engagement shaping ideation, co-design, and policy prioritization (source: authors)

Both tools mediated agency differently. AI and GIS shaped communicative space, redistributing agency between participants and technology. In Betania, real-time AI visualizations accelerated proposals and shifted initiative toward human-AI ensembles, while in Sankt Augustin, structured GIS categories legitimized resident input but required more guidance. These patterns illustrate digital agency, highlighting trade-offs in efficiency, inclusivity, and participation (Gonçalves et al., 2024). AI offered speed but risked opacity; GIS enhanced transparency and empowerment but demanded longer engagement, favoring younger participants with AI and older adults with GIS.

Building on these insights, the framework (Figure 5) positions AI and GIS as complementary paradigms: AI enables generative speed and co-production, while GIS ensures inclusivity and spatial grounding. Together, they form a hybrid model that extends the Four C model to participatory planning.

The proposed hybrid framework begins with GIS-based crowdmapping, consolidating citizen observations into auditable tiers of urgent needs. It then shifts to AI-supported divergent ideation, generating design concepts that broaden the solution space. These are re-grounded through multi-criteria analysis (climate, equity, deliverability), refined via participatory selection, and fed back into GIS for adaptive learning. By coupling divergent creativity with convergent evidence, the framework operationalizes the Four C model, aligns with co-creation literature, and reflects MDSD findings that inclusive digital participation supports resilience.

Within the indicated loops in the framework, creativity flows from mini-c sense-making sparked by maps and prompts, to little-c community creativity in workshops, and onward to Pro-c outputs as AI and GIS generate co-authored proposals and auditable evidence for policy dialogue. While Big-C breakthroughs are unlikely in participatory settings, the framework enables accumulated Pro-c contributions to scale into institutional innovations, consistent with Kaufman and Beghetto's model and Csikszentmihalyi's systems view of creativity.

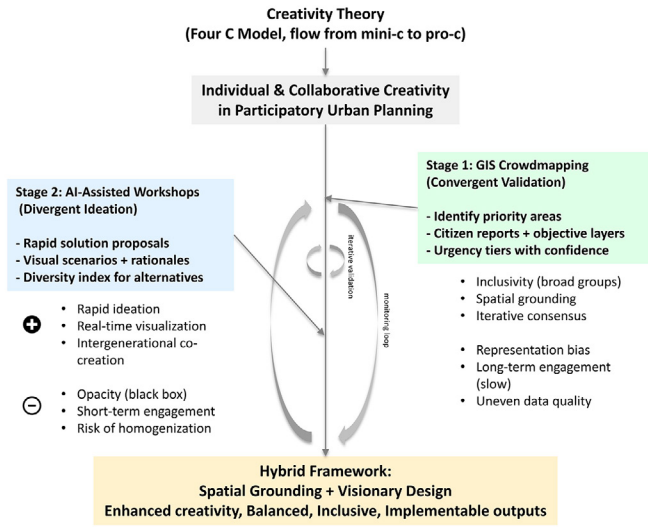


Figure 5. Framework linking AI-assisted workshops and GIS crowdmapping through creativity theory (source: authors)

This synthesis must account for structural biases and limitations. AI can reproduce dataset biases and favor dominant groups, as in Betania, while GIS, though more inclusive, may oversimplify when data quality is uneven, as in Sankt Augustin. Both face digital divides and institutional constraints, showing that tools alone cannot ensure equity. Hybrid approaches combining AI's generative speed with GIS's spatial grounding enhance creativity and feasibility: AI proposals validated by GIS tie visionary ideas to lived realities, supported by institutions.

Ultimately, the study demonstrates how digital tools mediate creativity in participatory planning, proposing a framework integrating divergent and convergent modalities. Structured methods mitigated limitations of secondary data. Positioning AI and GIS as complementary highlights hybrid approaches that balance efficiency and human agency, advancing digital creativity theory and supporting inclusive, green, resilient cities.

7. Conclusions

AI and GIS complement each other in mediating creativity and sustainability communication in participatory urban planning for urban greenery. AI enables divergent, real-time co-design, while GIS supports convergent, evidence-based validation of community input. In Betania and Sankt Augustin, AI shifted initiative toward human-AI ensembles, whereas GIS legitimized resident knowledge but required more facilitation. We propose a framework linking AI's generative speed with GIS's spatial grounding, balancing imaginative exploration with community-informed validation. Realizing this hybrid potential demands attention to digital divides, institutional constraints, and algorithmic bias through governance and digital literacy.

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