

Review

Unveiling Participation Dynamics: A Comparative Study of Green Infrastructure Practices

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Abstract

Outcomes for urban green infrastructure (GI) and low-impact development (LID) vary; thus, we ask when and how public participation affects performance. We apply a four-dimensional framework—breadth (who participates), depth (decision influence), identity (values/place attachment), and potential (incentives/capacity)—to conduct a literature review of Web of Science, Scopus, and Google Scholar. After deduplication and screening, 107 English-language studies were coded and compared across cases. Across contexts, early and representative engagement combined with clearly specified decision rights was associated with designs better aligned with local hydrologic and social conditions. Processes that attend to identity were consistently linked to stewardship behaviors. Institutionalized incentives and capacity, such as dedicated funding, defined roles, and feedback mechanisms, coincided with more durable operations and maintenance (O&M). Conversely, broad outreach without decision influence or feedback tended to remain tokenistic, with technical complexity and resource limits attenuating public influence. Effects appeared configurational rather than linear, with particular combinations of the four dimensions more often associated with success. Embedding codesign and feedback across the project lifecycle, pairing equity safeguards with community partnerships, and resourcing participation through clearly defined roles and incentives may help translate participation into resilient ecological and social outcomes.



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1. Introduction

The combined pressures of global climate change, rapid urbanization, and ecosystem degradation are posing significant challenges to traditional urban infrastructure in adapting and engaging in collaborative governance [1]. Long-term reliance on the expanding hard pavement and gray drainage systems has exposed systemic problems, including insufficient drainage capacity, water pollution, and urban heat-island effects [2]. In response, international urban governance has gradually shifted toward pathways emphasizing resilience, low-carbon development, and ecological cobenefits. Green infrastructure (GI), an integrative solution that embeds natural processes within urban systems, is attracting wide attention [3]. In practice, approaches such as the United States' BMPs/LID, the United Kingdom's Sustainable Drainage Systems (SuDS), and Australia's Water Sensitive Urban Design

(WSUD) prioritize distributed source control and green–gray synergies, progressively forming relatively mature regulation, technology, and management regimes [4–9].

However, engineering solutions alone are insufficient to guarantee successful performance across the full project life cycle. Cross-national practices demonstrate that public participation is critical during planning, construction, and operations and maintenance (O&M) [10,11]. Meaningful participation can enhance the democratic quality and scientific rigor of decisions, reflect diverse interests, and strengthen the social legitimacy and operational sustainability of projects—especially where facilities are embedded in residents’ everyday spaces and successful performance depends on use and maintenance behaviors [12–14]. In contrast, inadequate participation is often accompanied by risks, such as poor ecological outcomes, insufficient social acceptance, and subsequent abandonment. Regarding ecological performance, differences in evaluation metrics and hydrological contexts yield inconsistent results [7,8]. In terms of social acceptance, cross-national comparisons show that “inform–consult” modes rarely translate into durable support [15]. Finally, in later operation and management phases, unclear allocation of responsibilities and financing mechanisms often result in neglect or performance decay [16].

Despite broad consensus on the importance of participation, the field has not reached meaningful conclusions on whether, how, and under what conditions participation reliably improves project performance. Several reasons account for this outcome. First, the heterogeneity in hydrological contexts, spatial scales, and evaluation conventions result in unstable causal links between participation and ecological outcomes across projects, limiting external validity [7,8]. Second, tokenism and participation fatigue lead to an unresolved governance trade-off between “broad collaboration” and “implementation efficiency” [17,18]. Third, distributive equity and the risks of “green gentrification” remain salient, as urban greening upgrades in some locales coincide with rent premiums and the displacement of vulnerable populations [19,20]. Finally, outsourced maintenance responsibilities and fiscal constraints often drive a long-term decline in performance, with limited evidence on whether institutional embedding and capacity building can counteract this trend [15,16]. Accordingly, explanations that hinge solely on the presence or absence of participation are insufficient; instead, it is necessary to clarify conceptual and measurement boundaries and to explicate the pathways and boundary conditions of the distinct participation types and how they operate across heterogeneous institutional and social contexts.

Parallel to these debates, the existing knowledge base has three structural limitations. First, research and practice still tend to depict participation using surface-level indicators, such as frequency, satisfaction, or the number of channels, making it challenging to identify heterogeneous mechanism effects [17,21]. Second, the mediating or moderating roles of psychological identification and institutional incentives/capacity building remain only partially evidenced and lack systematic articulation within a coherent framework [22–24]. Third, comparative evidence across countries and institutional settings continues to be insufficient, limiting the transferability of conclusions and the robustness of policy generalization [15].

This study addresses these debates and gaps by synthesizing Arnstein’s “ladder of participation,” [10] collaborative governance theory [25], environmental psychology and social capital theory [26,27], and participation motivation/incentive models [23,28], systematically integrating and operationalizing four dimensions of public participation: participation breadth (diversity of actors and spatial coverage), participation depth (substantive influence and power sharing), participation identity (value resonance, place attachment, and community identity), and participation potential (policy incentives, institutional embedding, and resource provision) [10,23,25–31]. Using these “four types” as analytical slices,

the study employs success/failure contrasts to identify the causal chains and boundary conditions linking participation design, process characteristics, and outcomes (ecological performance/social acceptance/operational sustainability). The four elements do not act through linear causality; instead, they exhibit configurational effects in which the strength of any single dimension is more likely to yield stable performance only when appropriately combined with the others. Successful pathways typically feature institutionalized channels, feedback loops, and aligned configurations of resources and incentives. Conversely, mere coverage or attitudinal identification without institutional embedding/empowerment frequently appears in failed or constrained pathways (Figure 1).

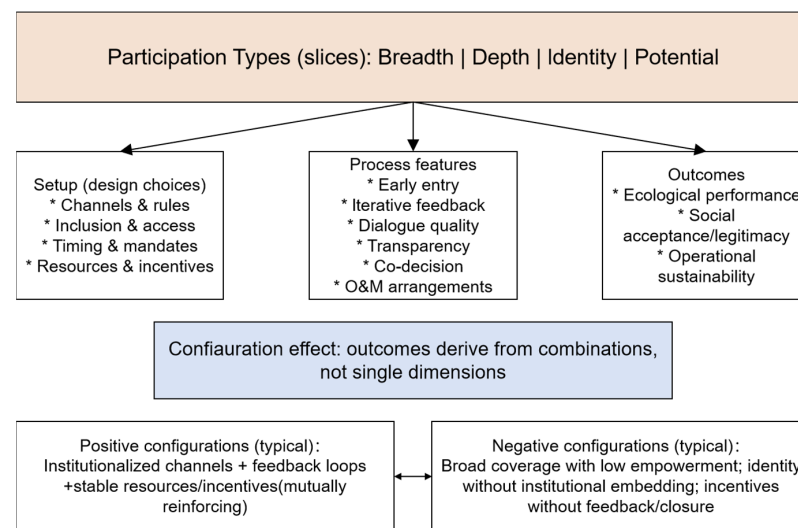


Figure 1. Configuration-oriented framework linking participation types to outcomes via setup and process features.

This study’s scope of inquiry comprises GI projects worldwide that are highly aligned with LID in their functional objectives and implementation mechanisms—namely, projects that share LID’s core mechanisms in distributed stormwater management, ecosystem service enhancement, and collaborative governance. Although the study focuses on research published in English for comparability, it does not exclude cases from non-English-speaking countries that appear in international journals. The study poses three research questions:

(RQ1) Which phase-sensitive indicators reliably operationalize the four participation dimensions throughout the GI project cycle?

(RQ2) Which combinations of those four dimensions, by phase, lead to better GI/LID outcomes (and which combinations fail)?

(RQ3) What simple, phase-specific actions can cities take to convert participation into durable performance?

This study conducts a systematic literature search with tiered screening, assembling cross-case comparative evidence. It conducts case-by-case analyses and thematic synthesis along the four analytical dimensions of breadth, depth, identity, and potential. By revealing the success–failure regularities of different participation configurations, it identifies applicability boundaries and potential success–failure modes across institutional and social environments. Theoretically, the study constructs an integrated analytical framework comprising the four dimensions—breadth, depth, identity, and potential—unifying and operationalizing the previously emphasized “breadth/depth” perspective with the newly foregrounded “identity/potential” perspective. Thus, it provides a systematic reconstruction of public participation types, proposes a reproducible review protocol and explicit criteria for judging success or failure, and offers transferable empirical insights for participation governance across multiple institutional settings.

2. Materials and Methods

2.1. Literature Search and Screening

This study conducts a systematic literature review to identify international case studies on GI. It performs a comprehensive search across the core academic databases, including the Web of Science and Scopus. Keywords for the search included “LID,” “Green Infrastructure,” “Public Participation,” and “Collaborative Governance,” together with their synonyms, and were expanded via Boolean operators (AND, OR) to broaden coverage. For example, “GI” was extended to “nature-based solutions” and “Sustainable Drainage”; “Public Participation” to “Citizen Engagement” and “Stakeholder Involvement”; and “Collaborative Governance” to “Co-management” and “Participatory Governance,” with synonym substitution adapted to each database’s controlled vocabulary. The publication window was limited to 2000–2025 to capture the modern development phase of LID and GI practice. Comprehensiveness and policy relevance were also ensured by targeting gray literature. Policy reports, project evaluations, and case reports related to GI and LID were retrieved from repositories of international organizations (e.g., ICLEI, UN-Habitat) and national and municipal government portals. Incorporating such nonpeer-reviewed materials enables capturing emerging insights into practice and the most recent project outcomes that may not yet appear in journal publications.

A multistage screening process was adopted to construct the final case sample. The database search yielded 367 records at the identification stage, which were reduced to 342 after deduplication. Title screening was then followed by removal of studies unrelated to GI, LID, or public participation, leaving 289 records. Abstract screening excluded works that lacked a substantive focus on participation or collaborative governance, resulting in 232 records. Sources lacking concrete cases or empirical project examples (e.g., purely theoretical papers or reviews without cases) were further excluded. Ultimately, 107 publications met the inclusion criteria and were retained for review. Figure 2 illustrates the screening process. A descriptive summary of this screening outcome is restated in the Results section to enhance transparency.

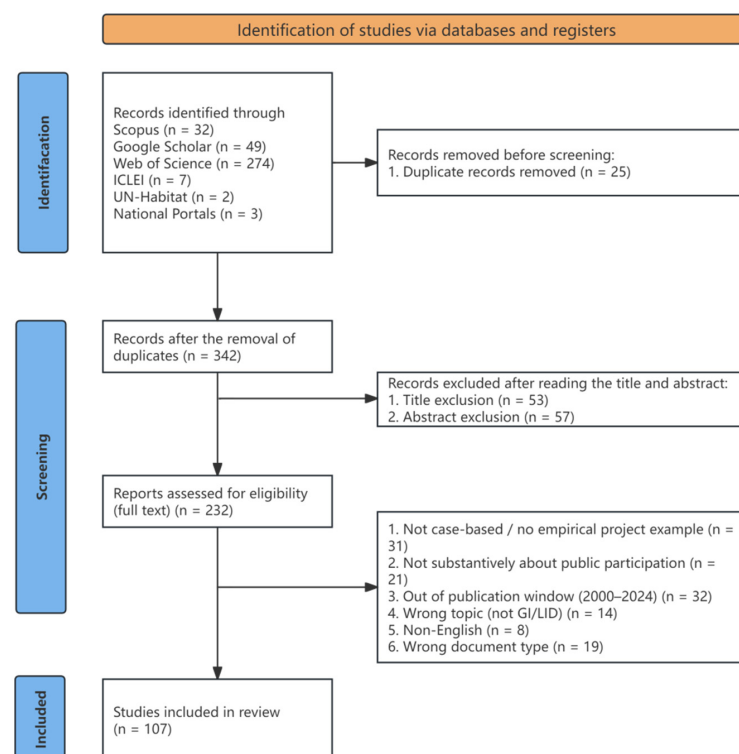


Figure 2. PRISMA 2020 flow diagram for study selection.

2.2. Data Extraction and Coding Scheme

All studies passing the full-text screening were incorporated into a structured coding table. For each study, we recorded the following information: bibliographic details (authors, year, journal), country/region, type of GI/LID involved (e.g., bioretention basins, rain gardens, green streets, multi-purpose parks), and project phase (planning, design, construction, or operation/maintenance). Subsequently, we analyzed the descriptions of public engagement and coded them according to four dimensions proposed in this review: breadth (scope of participating entities), depth (degree of participant influence), identity (alignment with local/community values), and potential (institutional or incentive conditions facilitating participation). Based on the level of detail in the original literature, each dimension was labelled as “explicitly present”, “implicitly present”, or “not reported”.

To enable cross-case comparison, outcome labels adhered to the original studies’ criteria: a case was coded as strength when authors reported both (i) the delivery and operation of green infrastructure/low-impact development facilities (ecological/hydraulic performance) and (ii) sufficient public acceptance or stakeholder collaboration to prevent major project delays or disruption [12,32]. Cases were coded as limitations when studies documented resistance, siting or distributional disputes, facility disuse, premature deterioration, or governance failure, and authors attributed these to inadequate participation mechanisms or design flaws [10,14–16]. Given some studies presented both positive delivery and participation-related problems, we retained an intermediate label “mixed (strengths with notable limitations)”. For comparative displays, such mixed cases are grouped under the aspect emphasized more strongly in the source, while the coding table preserves the mixed status.

During coding, we also documented the origin of participatory mechanisms: whether they stemmed from long-established statutory/routine planning procedures (common in North American and Western European cases) or were introduced through stakeholder consultation mandated by externally funded or donor-designed project requirements (observed in multiple Global South pilot projects). These contextual annotations will be utilized in subsequent discussions to highlight cross-regional variations. The full protocol and coding logic for this study are archived in the OSF repository (DOI: 10.17605/OSF.IO/Z3WVR).

2.3. Analytical Framework and Data Analysis

This study’s analytical framework integrates public participation theory, collaborative governance, environmental psychology, and institutional incentive models. In the governance practice of GI and LID, public participation is widely regarded as a key determinant of project performance. However, research has found that participation along a single dimension rarely ensures durability or effectiveness [10,31,32]. Accordingly, drawing on relevant theories and empirical findings, this study delineates four interrelated dimensions of public participation: participation breadth (breadth), participation depth (depth), participation identity/identification (identity), and participation potential (potential). We extract project characteristics, participation modalities, and outcomes from the selected literature and, using the four-dimensional framework, analyze how participation processes shape success or failure, revealing their underlying mechanisms and boundary conditions. Breadth refers to the horizontal inclusiveness of engagement, encompassing participant diversity and representativeness, as well as coverage across groups and geographies. Foundational work on who participates and who is represented in participation design underpins this dimension [21,33,34]. In environmental governance, inclusive processes that embrace diverse stakeholders broaden the informational base and social learning and are associated with stronger perceived legitimacy and support [29,35]. Recent syntheses further indicate that, alongside meaningful authority, broader inclusion is associated with improved envi-

ronmental outcomes [36,37]. In GI, breadth entails not just mobilizing more participants but, more importantly, incorporating diverse social groups and professional perspectives, thereby informing decision-making by plural forms of knowledge and social capital [38–43]. Depth highlights the influence and continuity of the public along the vertical decision-making process, spanning the continuum from one-off consultations to co-decision-making and power sharing [10,25]. The depth dimension draws on Arnstein’s (1969) “ladder of citizen participation,” which posits that participation may progress from “being informed” to “citizen control,” with each rung reflecting the strength of the public voice. Within a collaborative governance frame, Ansell and Gash (2008) further emphasized that genuine depth requires trust-building, sustained deliberation, and institutionalized empowerment. In GI/LID practice, depth, meaning substantive influence and power-sharing through the decision-making process, is closely associated with procedural legitimacy and public support [44], with robust collaborative processes resulting in improved implementation and environmental outcomes [45], and co-decision and institutionalized empowerment fostering a shared sense of responsibility [25]. At the psychological and social levels, identity captures the intrinsic drivers of engagement, including value congruence, community identification, and a sense of belonging [26,27]. Originating in environmental psychology’s place-attachment literature [46], the concept of shared identity suggests that emotional bonds and value identification with place can translate into sustained pro-environmental behavior. Social capital theory further posits that shared identity and networks strengthen willingness to cooperate and the capacity for collective action [47]. In the GI field, the identity dimension manifests as willingness, grounded in affective identification, and the sustained maintenance of projects and community co-governance through long-term social interaction and value resonance [46,48–50]. Potential denotes external enabling and incentive conditions, including policy incentives, benefit returns, and institutional support [23,28–30,32]. Rooted in institutional economics and incentive theory, the concept of potential suggests that participation is both value-driven and contingent on external rules and resource endowments. Frey and Oberholzer-Gee (1997) argued that external incentives can spur public action, although they may crowd out intrinsic motivation if poorly framed. In contrast, Willems et al. (2020) argued that policy incentives, resource provision, and institutional embedding are prerequisites for sustained participation. In GI governance, the potential dimension is reflected in supportive environments provided by governments and institutions—including funding security, role allocation, feedback mechanisms, and institutionalized incentives—converting latent willingness into durable participation practices [32,51–57]. Cases are classified on this four-dimensional framework, enabling cross-context comparative analysis of participation mechanisms [21,25,29].

After the coding sheet was completed as described in Section 2.2, we proceeded to the comparative analysis. Finally, a qualitative cross-case comparison was conducted by contrasting cases reporting predominant strengths and those reporting predominant limitations, and by examining how these configurations varied across the four project phases. This step allowed us to link participation patterns to reported outcomes and to identify recurring leverage points. Recurring patterns and critical factors were distilled within each of the four participation dimensions, with representative cases selected for illustration. The cross-case synthesis identifies the key mechanisms by which public participation, in varying configurations of breadth, depth, identity, and potential, shapes ecological performance, social acceptance, and long-term GI sustainability. Using this approach, practice-oriented insights and governance lessons are derived, which help explain why some participatory GI projects thrive while others struggle. Triangulation and cross-validation of evidence were undertaken wherever feasible to bolster the credibility of the findings.

3. Results and Discussion

3.1. Descriptive Results of Literature Screening

The initial search across Web of Science, Scopus and related sources identified 367 records. After removing 25 duplicates, 342 records remained for title screening. At this stage, studies that did not address green infrastructure or low-impact development (GI/LID), or that clearly lacked a public-participation or collaborative-governance component, were excluded, leaving 289 records. Abstract screening further removed papers whose focus was purely technical or modelling, or which treated participation only in passing, resulting in 232 records. At the full-text stage, we excluded (i) conceptual or commentary papers without empirical cases, (ii) non-English publications, and (iii) stormwater or drainage studies without a GI/LID element, which yielded 107 publications for final synthesis. The overall flow of records is shown in Figure 2.

In terms of geographical coverage, most of the 107 included studies were conducted in North American and Western European cities where participatory planning has been relatively institutionalized. A second cluster of studies came from East Asian programmes such as LID- or sponge-city-related stormwater management. A smaller number of papers reported donor- or project-driven pilot initiatives in cities in the Global South, where participation was introduced mainly to meet external safeguard or funding requirements.

With regard to study type, the final set was dominated by single-case and comparative case-study designs, often using qualitative or mixed-method approaches to describe how participation was organized and how local stakeholders responded. A smaller subset consisted of policy-evaluation or programme-review papers that discussed GI/LID participation at the municipal or national level. This composition indicates that the evidence base is rich in contextual and process-oriented accounts, but thinner on standardized, cross-sectional assessments. Taken together, this distribution shows that the evidence base is strongest for institutionalized, urban GI/LID participation in the Global North, with more limited coverage of donor-driven or project-based initiatives in the Global South; the representativeness of the sample should therefore be read with this imbalance in mind.

To further illustrate how the four participation dimensions were reported in practice, Tables 1–4 present a typological subset of 40 cases drawn from the 107 publications. These cases were not selected as four independent samples, but because the original studies offered sufficiently detailed descriptions to exemplify a specific dimension. Nine cases were used to exemplify participation breadth, ten to exemplify participation depth, nine to participation identity, and twelve to participation potential. Since several GI/LID projects reported more than one of these dimensions, individual cases could have been placed in more than one table; in such situations, the case was allocated to the table in which that dimension was most prominent in the source study. As a result, breadth and depth still appear most frequently, while identity was discussed mainly where local place-based or community values were at stake, and potential was only occasionally mentioned, often in the form of enabling municipal programmes or incentive schemes rather than as a formal design component. This pattern mirrors the distribution observed in the full set of 107 studies and helps readers assess the coverage and representativeness of the reviewed material. Overall, this subset confirms the pattern observed in the full corpus: explicit statements about who participated (breadth) are the most common, more detailed accounts of influence (depth) are available for about half of the well-described cases, while identity and potential tend to be reported more selectively, often in projects where community values, place attachment or enabling municipal programmes were central to implementation.

3.2. Applications of Public Participation

LID-centered GI projects typically progress through the sequential phases of planning, design, construction, and O&M. Because LID emphasizes distributed stormwater management, source control, and shared community responsibility, engineering and ecological design alone are insufficient to ensure success across the full life cycle. Inclusive public participation is crucial for securing the social legitimacy and technical feasibility of decisions as well as end-user support [10,14,17]. Effective stakeholder engagement embeds local knowledge into LID schemes, elevates the democratic quality of planning, and builds community ownership through early co-formulation, co-interpretation, and co-implementation. In contrast, symbolic or belated participation often breeds mistrust, depresses uptake, or results in declining facility performance [55,57]. In particular, narrow, last-minute, or purely “inform-and-consult” approaches seldom translate into durable public support, while unclear role allocation or weak community identification typically results in postconstruction neglect [5,7]. Accordingly, this section follows the project timeline to examine how four dimensions of participation—breadth (who participates), depth (influence), identity (values and belonging), and potential (institutional support and incentives)—operate and interact in each phase, drawing on cross-case evidence to show how they facilitate, or impede, project outcomes [38,39].

3.2.1. Planning Phase

During the planning phase, broad stakeholder participation—characterized by early and inclusive engagement—provides a solid foundation for rational, locally appropriate decision-making in LID projects [25,38]. The effectiveness of such engagement lies in its inclusiveness, with the participation of a wide range of actors, including residents, community organizations, nongovernmental organizations, experts, and businesses [32,42]. This diversity ensures that planning reflects a broad spectrum of knowledge and values. For example, in Atlanta’s Proctor Creek project, a collaborative network among the community, government, NGOs, and academic institutions helped expand the planning agenda to include environmental justice and public health. This approach balanced technical soundness with social acceptability [38]. A similar pattern is evident in Stockholm and Leipzig, where stakeholder workshops and surveys engaged businesses, residents, and public sector entities in the early stages. This type of collaboration facilitated identifying hydrological and ecosystem services and improving both public acceptance and the sustainability of planning outcomes [39]. Furthermore, the Index of Local Level Participation (ILLP) developed from surveys in 33 Polish cities quantified public participation using voter turnout and the share of stakeholder groups involved in city strategy processes, including municipal authorities, residents, third-sector organizations (NGOs), entrepreneurs, and investors, with targeted efforts toward youth and older adult engagement [58]. This broader involvement is associated with better alignment with stakeholder needs, conflict prevention, and greater awareness, conditions linked to greater public acceptance and more efficient policy implementation [59]. Early and inclusive consultation helps reduce planning biases and improve the execution of LID policy. The case of Athens highlights the risks of insufficient participation. Authorities offered only a 30-day consultation period and released 2,500 pages of documentation, widely perceived as symbolic rather than substantive, thereby eroding public trust in the planning process [57]. The case illustrates that meeting the minimum legal requirements for consultation is insufficient. Without authentic inclusiveness and responsiveness, planning processes can lead to public skepticism and social conflict [60–63]. This challenge is particularly critical for LID projects; because they are closely integrated into daily community spaces, they require not only technical solutions but also long-term community cooperation and support [60,64–68]. Representative cases are summarized in

Table 1, which compares participation across diverse urban contexts. The table highlights how early, inclusive, and multistakeholder involvement is better aligned with local needs, while tokenistic or delayed engagement frequently results in distrust and resistance.

In addition to participation breadth, participation depth is equally important for meaningful public involvement. Enabling the public to influence decision-making rather than merely providing information is essential [10,25]. Given that LID infrastructure is typically small scale and embedded within neighborhood microspaces, its effectiveness generally depends on residents' daily use and support [11,12,49]. When public participation lacks depth, planning outcomes may appear sound in theory but fail to reflect the practical realities of community life [69–71]. Although not explicitly designed for LID, the Environmental Quota Program in São Paulo, Brazil, provides valuable insights. Through a series of stakeholder workshops, residents, developers, and academics jointly developed planning indicators and policy tools [72–74], ensuring alignment with local needs and fostering public support [72–76]. Comparative studies on Strategic Environmental Assessment (SEA) in Europe and Asia have shown that when public involvement is delayed until after key decisions involving site selection or design have already been made, citizens are rarely able to influence outcomes [77–82]. This may result in frustration, legal challenges, and project delays [79,81,83]. These findings are especially relevant for LID, as decisions regarding the location, landscape design, and drainage paths directly affect residents' daily experiences [77,78,81]. A lack of early, deep engagement frequently results in resistance and low acceptance in later stages [79,81].

Participation identity also plays a vital role during the planning phase by fostering a sense of community belonging [65]. Unlike traditional gray infrastructure, LID facilities are generally located in residential areas and integrated into daily life; thus, they are more likely to become symbols of community identity [84,85]. Involving residents in the early goal-setting process helps cultivate a sense of psychological ownership, with residents viewing the infrastructure as something they collectively share and value [49,86]. In China's Sponge City pilot programs, typical LID elements, such as rain gardens and permeable pavements, have been widely implemented [85,87]. Following initial participatory dialogues during the planning stage, many residents felt their perspectives were acknowledged, which contributed to long-term support for the facilities [88,89]. In contrast, communities may perceive projects as externally imposed when they lack formal engagement, potentially leading to resistance. This has been observed in SEA cases in several contexts [90,91]. For LID implementation, fostering a sense of shared ownership is essential. Only when residents consider the infrastructure as part of their own community will they take responsibility for its maintenance and use, which is key to achieving both ecological and social benefits.

Participation potential, defined as the capacity to stimulate ongoing engagement through institutional support and incentives, is also essential to long-term success [92,93]. Institutional frameworks and incentive mechanisms are necessary to fully realize the potential of public participation during the planning process [28,32,94]. LID projects require long-term and detailed management. Without continuous incentives, public engagement is likely to diminish after a project's launch [92,93,95–98]. Evidence from the ILLP index in Poland shows that cities with higher voter turnout and more inclusive planning approaches tend to have smoother policy implementation [58], suggesting that institutional rewards and structured participation mechanisms can effectively mobilize broad-based support in the early stages of project development. Conversely, when formal consultation channels are lacking, the public often feels excluded, resulting in disengagement [95,96,98]. The case of Wrocław provides further confirmation of this dynamic. Although planners collected input through surveys and mapping activities, the lack of meaningful power-sharing thwarted

the effective translation of residents' goodwill into concrete outcomes [99]. This risk is particularly significant for LID facilities, which require ongoing community feedback and routine maintenance to sustain their intended functions [65,98].

Table 1. Case-based evaluation of participation breadth.

No.	Case Location	Key Features of Participation Breadth	Strengths or Limitations
1	Proctor Creek, Atlanta, USA	Multistakeholder collaboration among community, government, NGOs, and educational institutions; covered education, design, and maintenance	Enhanced social acceptance, raised environmental responsibility awareness, established long-term governance networks [38].
2	Stockholm & Leipzig, Europe	Workshops, surveys, and interviews engaging officials, businesses, residents, and NGOs; consensus-oriented negotiation mechanisms	Improved recognition of ecosystem services, enhanced adaptability and sustainability of plans [39].
3	Poland (33 Cities)	Quantitative evaluation via ILLP index; diverse participation including youth, NGOs, and private sector	Higher acceptance and efficiency of municipal policies [58].
4	Suzhou, China	Institutionalized multichannel participation: resident consultation, online voting platforms, community deliberations	Broadened participation base including residents, enterprises, and experts; institutionalized feedback loops [40].
5	Mining projects in Chile (Chile)	Voluntary early public participation opened hearings and workshops to a wide range of affected stakeholders (local residents, community leaders, NGOs, and municipal officials), broadening both the number and diversity of voices included in the EIA process.	In Chilean mining EIAs, early voluntary hearings and workshops enabled affected communities to raise concerns and improved participation despite persistent power asymmetries [83].
6	Japan (National Social Media Participation)	Government-led digital platform for nationwide low-carbon lifestyle promotion	Lacked institutionalized decision-making channels; citizens remained largely "audience" [41].
7	Houston, USA (COVID-19)	Shift to online engagement via Zoom, surveys, and forums	Digital divide excluded vulnerable groups; weak trust and interaction quality; doubts over fairness [43].
8	Berlin, Germany	Community gardens initiated by citizens; local residents engaged in design and daily management; later municipal authorities attempted to impose stricter governance without adequately addressing residents' demands	Top-down attempts to formalize control without sufficient resident inclusion created tensions and forced the city to renegotiate governance arrangements with local gardeners [42].
9	Athens, Greece	Tokenistic public consultation: only 30 days for feedback on a 2500-page technical document; limited involvement of citizen organizations and academics	Consultation perceived as a formality; citizens' suggestions largely ignored; limited community organization weakened follow-up; led to distrust and resistance during implementation [57].

3.2.2. Design Phase

Public participation during the design phase aims to broaden participation breadth, ensuring that the diverse needs of various social groups are reflected in specific site plans and technical solutions. Following the planning stage, broad conceptual visions become detailed site layouts and design interventions. Public input at this stage is essential for ensuring that the resulting designs are user friendly, contextually appropriate, and widely supported [85,100–105]. The design of LIC practices should systematically incorporate users' preferences and constraints to avoid "functional compliance but experiential failure." In the case of Portland's Green Streets, residents voiced concerns about the visual appearance, safety, and maintenance responsibilities of curbside bioswales, which tempered initial support. Perceptions gradually improved as engagement deepened and benefits became visible [106]. Similarly, in a survey across six neighborhoods in the UK, some respondents voiced concerns about the aesthetics and safety of rain gardens and bioretention areas, decreasing their willingness to support or use such infrastructure [107]. Cities have adopted creative strategies to expand participation breadth in the design stage. For example, in Hamburg, Germany, the CLEVER Cities initiative employed cocreation labs (CALs), school-based codesign sessions, and workshops to engage groups that are typically underrepresented [108]. These approaches broadened the scope of design discussions, fostered a sense of participation and identity, and laid the groundwork for future collaboration through experiential learning [108,109]. These examples demonstrate that broad participation in design is not only a form of quality assurance but also preconditions the long-term stewardship of LID facilities.

Beyond inclusivity, participation depth during the design phase is critical for meaningfully incorporating public feedback into design revisions. Gathering opinions is insufficient; citizens must be empowered to influence design decisions [10,25]. Common mechanisms to facilitate such influence include community design workshops, design review panels with citizen representation, and immersive technologies, including virtual reality or spatial simulations, to elicit detailed responses [42,110]. These tools enable residents to view drafts and actively participate in iterative revisions. In Berlin (Germany) and Turku (Finland), planners used Public Participation GIS (PPGIS) platforms to collect spatially explicit input from hundreds of residents [111–114], which informed adjustments to planning parameters and revealed the underrepresentation of older residents and nonnative language users [42,110]. Such iterative engagement processes provide empirical justification and enhance the social legitimacy of design outcomes. These methods are especially important for LID facilities, as rain gardens and bioretention areas are often embedded within microscale street and neighborhood environments. Ignoring the needs of specific user groups can result in neglect or low utilization postimplementation. In the EU's CLEVER Cities project, cities followed a 16-step cocreation pathway—ranging from information gathering to collaboration and co-decision-making—while defining stakeholder roles and closing feedback loops, converting public input into concrete design features [108,109]. PPGIS studies further stress the importance of maintaining representativeness and identifying value conflicts, cautioning against technological or linguistic barriers that may marginalize vulnerable populations [42,110]. These insights underscore the need for multistage negotiation and empowerment, even at the community scale, which enhances transparency and prevents residents from disengaging due to inaccessible technical language [115–117]. Taken together, these cases underscore the need for repeated engagement and a genuine incorporation of public perspectives to achieve participation depth. If community input is purely symbolic—such as last-minute consultations with no intent to modify the plan—key issues may go unnoticed, and sustained public support becomes unlikely [97,115,116]. Conversely, substantively integrating public feedback into the design process, especially in everyday

LID contexts, can drive functional alignment and community acceptance [76,115,116,118]. Drawing on these observations, Table 2 presents a comparative overview of participation depth across international cases, showing how institutionalized workshops, structured consultation frameworks, and digital tools (e.g., PPGIS) can transform symbolic consultation into substantive influence on decision-making.

Public participation in design can also strengthen a sense of participation identity, reinforcing community identification with the project and fostering a sense of ownership [49,86]. During the design phase, abstract plans gradually evolve into tangible spatial forms and facility details, allowing the public to emotionally connect with the project [42,119]. This is particularly important for decentralized stormwater management measures, such as LID facilities, where rain gardens and bioretention areas are embedded in residents' daily environments [120,121]. Without a sense of belonging, these facilities risk neglect or poor maintenance [42,121]. Case studies have shown that involving citizens in design decisions helps cultivate pride in and attachment to the project. Activities such as co-drawing site plans, community design competitions, and building physical models help residents better understand what future infrastructure will look like and how it will function. This understanding makes the project feel more "real," fostering a stronger sense of responsibility for its success. Research indicates that when people contribute their ideas and creativity in the design stage, they are more likely to view the outcome as "our creation" rather than an externally imposed intervention, minimizing the likelihood of neglect or vandalism [42]. Even when not all preferences can be accommodated, transparent negotiation among the different design options can improve public acceptance. When citizens see that diverse views are treated fairly and balanced during the design process, they feel respected and are more likely to support the final decision [80,122,123]. This process effectively plants the "seeds of stewardship" in participants' minds, encouraging them to consider future infrastructure as a community asset rather than an external imposition. For example, in the Green Alley transformation in Quebec, Canada, residents codesigned the greening plan with landscape architects, selecting plant species and spatial layouts [119]. Upon completion, residents expressed a strong sense of ownership, referring to the green spaces as "our backyard" and actively participating in maintenance [119]. More broadly, this community identification and commitment, developed through collaborative design, is significant for urban green spaces and for decentralized stormwater management. A study in Minnesota found that household rain garden owners used the facility more frequently and were more willing to maintain it when the final design and upkeep aligned with their original expectations [120,121]. Similarly, Feng et al. (2022) found that when landscape-based stormwater infrastructure reflected residents' preferences for aesthetics, convenience, and functionality during design and maintenance, public acceptance and satisfaction increased significantly. Since rain gardens and bioretention systems also rely heavily on everyday use and upkeep, integrating residents' perspectives at the design stage significantly improves the long-term performance and sustainability of LID facilities [120].

Activating potential is equally critical to fully leverage public input during the design phase [32,42]. Whereas the planning phase relies on formal regulatory procedures, the design phase benefits more from creative and engaging approaches that attract interest while designs are still flexible [109,124,125]. For instance, local authorities in Hamburg-Wilhelmsburg employed interactive exhibitions and child-friendly workshops to involve groups that are typically underrepresented. These methods expanded participation breadth and strengthened participation identity through "learning by doing" [124]. In Bratislava and Košice, the Urban Forests initiative assigned formal roles—such as community forest stewards—to residents, encouraging early engagement and sustained responsibility throughout the design process [125]. Similar institutionalized practices were observed

in the LID demonstration project in Xixian New District, China, where a community advisory mechanism allowed residents to participate in planning bioretention ponds and rain gardens, forming a continuous responsibility chain from design to maintenance [89]. Stimulating participation potential during the design phase also requires also depends on maintaining continuous feedback loops. When design teams publicly respond to community input—explaining which suggestions were adopted, which were not, and why—it demonstrates respect for contributors and also strengthens public responsibility and willingness to support and maintain the facility [121]. These examples illustrate that activating potential goes beyond increasing the number of participants; it involves assigning roles, organizing creative competitions, and offering immersive experiences that allow people to feel their input has a lasting impact on LID infrastructure [65,126–128]. Such mechanisms contribute to the accumulation of social capital that supports a project’s ongoing use and upkeep, as well as preventing the risk of “build but not use” and laying a foundation for long-term sustainability [65,126,129].

Public participation in the design phase is crucial for refining GI planning and making it more human centered. Successful engagement at this stage is characterized by integrating interactive tools, assigning roles, and establishing closed feedback loops [125,130–132]. For instance, in Hamburg’s CLEVER Cities initiative, CALs and the 16-step cocreation pathway enabled the public to participate in iterative revisions through workshops, school-based codesign sessions, and visualization tools—while the design remained flexible [108]. This allowed feedback to be “seen and adopted,” enhancing design fit and social legitimacy while also building social capital for future use and maintenance [108,109]. In the context of LID, combining such mechanisms with spatial participation tools, such as PPGIS, allows for more precisely identifying block-scale user needs and helping avoid the issue of “functional compliance but experiential failure” [42,110]. If participation is limited to symbolic consultation—or if residents are approached only at the end of the process—public feedback has little chance to influence outcomes, resulting in dissatisfaction. When compounded by a lack of representativeness (e.g., older adults, nonnative language speakers) and communication barriers, the result is frequently low usage and reduced satisfaction in the postimplementation phase [42,110]. User perceptions and experiences are especially vital for LID facilities, where discrepancies between actual experiences and residents’ initial expectations lead to a decline in satisfaction and voluntary maintenance, eroding long-term performance [120,121].

3.2.3. Construction Phase

As LID facilities transition into the construction phase, the role of public participation shifts from cocreation in planning and design to supervision, collaboration, and the building of mutual trust during implementation [29,31,133]. Unlike traditional gray infrastructure, LID systems involve microscale components such as bioretention cells, permeable pavements, and infiltration trenches, whose long-term performance heavily depends on the quality of construction practices and environmental management during installation [50,133]. Institutionalizing the breadth of participation through transparent information disclosure, multichannel feedback systems, and rapid-response oversight networks strengthens regulatory compliance, public trust, and project legitimacy [50,133]. In Suzhou’s Sponge City initiative in China, early-stage mechanisms, including resident consultations, online voting, and neighborhood forums, were expanded in the construction phase to include public information displays, on-site community liaisons, and digital feedback [40,101]. Residents reported issues such as noise, dust, and road blockages in real time. At the same time, contractors responded and took corrective action within a fixed timeframe, establishing a broad-coverage, fast-response feedback loop [42,101].

Similarly, in the Proctor Creek project in Atlanta, USA, a network of community groups, NGOs, universities, and municipal authorities extended to the construction sites to jointly monitor traffic flow, vehicle washing stations, and sediment control measures—translating broad-based participation into effective compliance [29,38]. In New Zealand’s Long Bay and Flat Bush developments, early-stage consensus building during structured planning led to specific site rules during construction, including sediment management, ecological buffer protection, and phased fencing adjustments—integrating community oversight with construction standards and minimizing conflicts and disputes over legitimacy [134]. Overall, participation breadth in the construction phase involves embedding diverse groups into real-time supervision and feedback systems—turning “eyes on the street” into active guardians of construction quality. Conversely, the construction processes that lack transparency and feedback channels create public suspicion or protests, disrupting timelines and undermining sustainability [31,57]. Therefore, deeply embedding public oversight and transparent communication into the construction management workflow is critical for ensuring the successful delivery and ecological functionality of LID projects [50,133].

Table 2. Case-based evaluation of participation depth.

No.	Case Location	Key Features of Participation Depth	Strengths or Limitations
1	São Paulo, Brazil	Early-stage and institutionalized involvement through workshops and consultations; broad engagement of citizens, academics, and developers.	Enabled diverse stakeholders to influence the design of indicators and measures, strengthening social legitimacy; however, technical complexity limited lay citizens’ ability to contribute beyond value-based input [72].
2	Wilhelmsburg, Hamburg, Germany	Innovative participation tools: interactive pavilions, child-inclusive workshops, intergenerational cocreation	Improved park usability, strengthened community ownership, sustained civic participation [108,109].
3	Taoyuan, Taiwan	Establish diverse groups such as farm pond workers, farmers, environmentalists, and community kitchens to ensure the continued involvement of different groups of people; regularly organize environmental education workshops and farm pond maintenance activities.	Residents exert substantial influence through institutionalized channels; however, due to limitations in expertise and resources, some technical aspects still require the support of external experts [135].
4	Berlin, Germany	PPGIS survey collected socioperceptual data on cultural ecosystem services across the city; citizens marked meaningful green spaces and evaluated their values and uses.	Enhanced depth of participation by integrating citizens’ place-based perceptions into planning, improving representativeness and identifying service gaps. However, limited representativeness due to underrepresentation of older and non-German groups reduced inclusivity [42].
5	Turku, Finland	730 residents used PPGIS to mark 2,270 outdoor sites and assess recreation, aesthetics, and nature connectedness.	Captured patterns of outdoor recreation, nature contact and perceived well-being, providing spatial evidence for pandemic-responsive green space planning [110].

Table 2. *Cont.*

No.	Case Location	Key Features of Participation Depth	Strengths or Limitations
6	Central Europe (SK, CZ, AT, HU, RO)	Developed a five-stage participation framework (informing, consulting, dialoguing, engaging, empowering) involving governments, NGOs, and communities.	Enabled structured, progressive stakeholder engagement and trust-building; challenges included trust deficits and technical language barriers [125].
7	Europe (multiple cases)	SEA processes often introduced public participation only at late planning stages, limiting opportunities for meaningful input.	Public feedback could not influence key decisions, leading to delays, legal disputes, and reduced legitimacy of outcomes [90].
8	Mainland China and Taiwan	Public hearings held after key decisions (e.g., site selection, design) were already made	Triggered mass protests and mistrust, weakening project legitimacy [91].
9	Global Dam Projects	Large dam projects lacked inclusive early consultation; affected communities informed after decisions.	Caused large-scale conflicts, legal disputes, and project delays [55].
10	China (Pilot Sponge Cities)	Residents expressed willingness to pay for maintenance of LID facilities via surveys, but direct involvement in maintenance activities remained low.	Showed financial willingness but lacked substantive engagement in hands-on maintenance; participation remained at consultative level rather than active decision-making or implementation [88].

Participation depth in the construction phase does not entail the public physically engaging in construction activities. Instead, it refers to how citizens influence the quality and technical details of GI/LID components through institutionalized mechanisms such as prototype reviews, joint inspections at key milestones, and routine monitoring procedures [50,133]. In the Trenčín pilot of the Central European TRANSGREEN project, a progressive collaboration model—comprising information release, public consultation, thematic dialogue, conflict negotiation, and stakeholder empowerment—was extended into the implementation phase. This iterative engagement facilitated site-specific discussions and feedback loops on design details and usage impacts, improving the likelihood that public input would be meaningfully acknowledged and incorporated, while enhancing the project’s responsiveness to local needs and reinforcing trust [31,125]. Bottom-up community initiatives can also create a type of “soft oversight” during construction and early operation. For example, in Longtan’s Gaoyuan community on the Taoyuan Plateau, the local community development association organized residents to participate in pond-area construction and management (e.g., artificial floating islands), planting (organic/nontoxic crops and aquatic plants), and regular maintenance with long-term ecological surveys in an effort to revitalize the Xia-Dian-Zi farm pond [60]. Although not formally labeled LID, the project’s focus on localized retention, infiltration, and purification closely aligns with distributed source control principles. Mobilizing local knowledge and collaboration networks generated ecological and social co-benefits [135,136]. Urban stormwater practices further reveal that without institutionalized channels to embed public input into implementation and maintenance, participation remains superficial and consultative, failing to influence operational performance or shared responsibility. In contrast, deep participation can evolve into sustainable infrastructure performance and accumulate social capital through clear role designation, regularized feedback systems, and co-maintenance arrangements [31,88,89].

These examples illustrate a key governance principle: a phased collaboration process ensures public input remains visible, traceable, and actionable during implementation. When coupled with localized knowledge and organized engagement, these practices help anchor LID-aligned principles—such as source control and on-site mitigation—within the construction and maintenance of urban infrastructure [65,137–140].

In urban stormwater governance centered on LID, disturbances during construction can become opportunities for community identity formation and institutional trust—if public participation is intentionally designed and institutionalized. Research shows that continuous resident involvement in construction, planting, and self-management helps build social capital and enduring interaction networks [141]. Embedding this logic of participation into low-risk, highly visible components of neighborhood-scale LID installations—such as bioretention planters, depressed green spaces, or permeable pavements—allows communities to move beyond one-off consultations and contribute substantively to the infrastructure itself, while narrowing the psychological gap between “inside the fence” and “outside the fence” [142–146]. A case in point is the Green Alley retrofitting project in Quebec, where resident-led greening and daily maintenance fostered long-term stewardship of public space and a shared sense of value, despite the absence of material incentives [119]. At a broader governance level, the “mosaic governance” model, which entails multiactor collaboration and coproduction, provides a pathway to connect grassroots participation with city-scale stormwater management standards, enhancing institutional embeddedness and social legitimacy [49,147,148]. In China’s Sponge City program, a chain of perceived elements, ranging from conceptual understanding and ecological/landscape benefits to trust in local government, correlates positively with public satisfaction and project support [86,149]. These findings demonstrate that communication transparency, feedback responsiveness, and iterative engagement during construction are not peripheral but central levers for building public identification and support. Moreover, through place-based attachment and shared experiences, attitudinal support becomes tangible environmental stewardship behaviors [27,42]. In contrast, shallow participation or one-off activities—such as geotagging opinions without follow-up—tends to erode value alignment, and governance capacity remains underdeveloped [99]. In sensitive social contexts, the absence of early negotiation and feedback loops during opaque construction phases can trigger resistance and delay, and increase governance costs [56,150]. Synthesizing these insights, LID construction management should be guided by a causal chain of “representative participation—empowerment and feedback closure—identity formation—autonomous stewardship.” This involves opening safe, observable construction activities for public co-engagement; establishing traceable systems for recording, reviewing, and integrating community input; and embedding community experiences into urban governance structures through multistakeholder collaboration. When aligned with original case facts, this type of institutional design can amplify the positive impact of participation during construction on project performance and long-term resilience [125]. The role of identity-driven engagement is further detailed in Table 3, which summarizes cases in which residents’ sense of ownership, place attachment, and shared values occasioned long-term GI stewardship.

In the construction of LID-based stormwater infrastructure, the implementation phase should be treated not as a closed technical interval but as a vital window for collaboration and co-governance [15,32]. Several mechanisms must be embedded from the outset to activate and sustain public potential. First, disclosing routine information disclosure and providing accessible communication channels are essential, with key milestones, critical construction activities, temporary drainage adjustments, and traffic impacts published both on-site (via physical boards) and online (via dashboards), accompanied by clear contact points for consultation. Such transparency reduces uncertainty and improves stake-

holder engagement and responsiveness [32,151]. Second, establishing a “report–respond–feedback” loop is vital. Disturbance issues—such as dust, noise, barricade obstruction, or silt accumulation—should be addressed via hotlines or app-based platforms, with service-level agreements and confirmation receipts to ensure accountability. Through this approach, external incentives lead to sustained participation [152]. Institutional embedding can draw from models that integrate social action into formal governance structures. For example, liaison or oversight committees during construction—comprising neighborhood representatives and prior codesign participants—can conduct routine reviews and real-time monitoring. These organizational setups do not alter the nature of original cases but offer transferable governance templates for LID project implementation [153]. From a motivational standpoint, lightweight incentives and public recognition have been shown to correlate with pro-environmental behavior in organizational settings [154]. A feedback loop built on “small incentives–visible outcomes–positive reinforcement” may motivate community-based construction supervision—particularly if linked to perceived rainwater performance outcomes. Demonstration zones, pre-/post-flooding comparisons, and visualization of drainage and water quality data can provide immediate cues that motivate participation and align with the observed correlation between environmental awareness and willingness to support or pay [94,155]. Platform continuity is also critical. Research on nature-based solutions (NBS) shows that when collaborative platforms are active only during planning or codesign but fade during delivery, public interest and trust often erode [156]. Therefore, extending these platforms into the construction phase and clarifying their roles in information verification, conflict resolution, site visits, and prioritization of concerns are important [32]. When information transparency, closed feedback loops, aligned incentives, and institutional embedding function in concert, LID projects are more likely to shift passive interest toward active, sustained engagement. These mechanisms also lay the organizational and psychological groundwork for future O&M (O&M) co-governance [151,152].

Successes and challenges highlight a shared conclusion: the sustainability of participation during the LID construction phase depends on the coherence and executability of governance arrangements. Maintaining open and accessible communication mitigates uncertainty and stabilizes expectations; embedding complaints and responses in traceable systems enhances accountability and response efficiency; and incorporating public roles into formal processes ensures that feedback is visible, recorded, and actionable. Pairing lightweight incentives with real-time visualization of rainwater performance strengthens perceptions of outcomes and identity formation. Extending these mechanisms throughout the delivery phase leads to internalizing community oversight as quality assurance, later manifesting in protective behaviors and social capital during O&M. In contrast, breakdowns in communication, failed feedback systems, or institutional gaps may reduce participation to symbolic gestures, increase conflict risks, and undermine long-term ecological and social outcomes. Therefore, LID construction management should prioritize a coordinated framework of transparent communication, feedback closure, institutional embedding, and performance visualization—implemented through small-scale, actionable management units—to synchronize construction quality with public collaboration and establish a replicable institutional foundation for long-term resilience and shared governance.

Table 3. Case-based evaluation of participation identity.

No.	Case Location	Key Features of Participation Identity	Strengths or Limitations
1	Quebec City, Canada	Residents initiated greening actions via participatory workshops and project committees supported by Nature Québec, engaging in shared planning and budgeting.	Fostered strong community cohesion and environmental stewardship, but long-term participation declined and excluded less-connected social groups [119].
2	Multiple cities in Europe (e.g., Rotterdam, Berlin, Barcelona)	Citizens engaged in co-planning and implementation of GI (e.g., rain gardens, urban parks) based on shared sustainability values, not economic incentives	High internalized motivation; strengthened social identity and civic responsibility, fostering coproduction and long-term policy resilience [49,147].
3	Multiple NBS sites in Europe (including disadvantaged communities)	Residents participated in agenda-setting and monitoring of NBS projects as coproducers, especially in marginalized neighborhoods	Rebuilt environmental confidence and local identity; reinforced sense of ownership and inclusion [42].
4	Poland (large cities)	Residents engaged through long-term participation in local elections, municipal hearings, and urban planning discussions, covering diverse social groups and decision-making arenas.	Fostered a strong sense of “ownership” of urban governance, with identity-based trust driving transformation from passive observers to active participants [39].
5	Antwerp, Belgium	Urban Living Lab institutionalized cross-sectoral collaboration; provided formal channels and role clarity for citizen input	Effectively activated early-stage potential; citizen input integrated into planning documents [32].
6	Elvas and Faro, Portugal	Residents engaged via large-scale surveys assessing perceptions and preferences toward GI for climate adaptation.	High recognition of GI’s ecological and climate adaptation benefits; participation limited to opinion expression without direct involvement in design or decision-making [74].
7	China (Four pilot sponge cities: Nanjing, Suzhou, Wuhan, Changsha)	Residents engaged through community surveys, focus groups, and public meetings; assessed perceptions of ecological and social benefits.	Strong recognition of Sponge City concept and ecological benefits; enhanced “sense of being heard” and identity-based support for implementation [86].
8	Wrocław, Poland	Residents used PPGIS and surveys to express preferences on GI locations	Participation was limited to one-time data collection; lack of sustained dialogue and decision-making power prevented transformation of ecological recognition into governance capacity [99,114].
9	Latin America Cities	Projects advanced through top-down approaches without incorporating community identity and long-term attachments	Lack of early consultation and dialogue led to protests, social mobilization, and legal disputes; conflicts delayed projects and increased costs [56,150].

3.2.4. Post-Management Phase

As GI/LID facilities enter the post-management phase, their performance increasingly depends on routine inspections and standardized light maintenance, owing to their distributed, neighborhood-embedded nature. Rain gardens, bioretention areas, infiltration trenches, and permeable pavements require ongoing technical care and institutionalized collaboration that integrates multiple stakeholders into a shared maintenance network [50,133]. Case studies show that participation breadth can take the form of a sustained “perception–feedback–response” mechanism during the post-management phase without altering the original findings of previous research. In Atlanta’s Proctor Creek green stormwater initiative, long-term collaborative relationships were established among residents, local government, NGOs, and universities. Public education and capacity-building were extended from the implementation phase into maintenance, supporting system performance and social acceptance [38]. Similarly, in Suzhou’s Sponge City program, early mechanisms, such as resident representative consultations, online voting, and community forums, were continued into the post-management phase, serving as channels for information exchange and feedback integration that supported problem resolution and a closed-loop institutional system [40,157]. The cocreation experience in Hamburg’s Wilhelmsburg district also demonstrates that intergenerational and cross-cultural participation can broaden the spatial usage base and improve on-site feedback quality. This provided a strong social foundation for daily maintenance and adaptive fine-tuning of LID features [124]. From a governance perspective, broad participation enhances early detection and timely resolution through role differentiation and redundant monitoring systems, reducing the risk of performance loss from unreported issues, transforming “users” into long-term “stewards,” and reinforcing shared ownership and collaborative governance by accumulating social capital [42,158]. Conversely, without broad-based engagement and efficient communication channels, post-management can become overly dependent on small professional teams. The timeliness of inspection and maintenance cannot be ensured, increasing the probability of system clogging, vegetation decline, and the deterioration of hydrological functions [50,133].

Enhancing the depth of public participation entails institutionalized co-governance. A closed-loop process of inspection–feedback–execution–review can transform communities from assistants into substantive cogovernors of LID subfacilities, including rain gardens, bioretention cells, and constructed wetlands [10,25,31]. This transformation is first reflected in the division of responsibilities between community-led daily maintenance and technical support from government departments. For instance, in the revival of agricultural ponds in the Taoyuan Plateau Community, long-term community involvement in routine inspections, environmental education, and site maintenance was combined with assistance from governmental agencies and academic institutions [60]. This collaboration enabled the “pond–wetland” system to perform hydrological retention and ecological restoration functions consistent with LID principles, while also building stable social capital and organizational capacity [135]. Digital tools can further turn residents’ experiences into verifiable evidence for maintenance [159–161]. PPGIS practices in Berlin, Germany, and Turku, Finland, have employed online maps and spatial annotations to document public perceptions of flood-prone areas, usage preferences, and cultural ecosystem services [42,110], which are then quantified into actionable planning and management priorities. Such approaches can be directly adapted to refine LID maintenance priorities, including vegetation succession, inlet and overflow management, and other decisions [42,110]. Additionally, a staged collaboration process improves the traceability of public input. The Central European TRANS-GREEN project’s procedural framework of early notification, public consultation, thematic negotiation, conflict mediation, and partner empowerment offers a transferable model for

LID post-management. By linking each round of inspection issues to subsequent follow-up actions and review results, public suggestions are ensured of being addressed in future operational cycles and formally documented in institutional records [31,125]. Without clear responsibilities and feedback mechanisms, the public—even when equipped with knowledge or a willingness to contribute financially—is relegated to reporting issues to property managers or government authorities, falling short of actual co-governance. This hampers stable investment in maintenance and limits performance improvements [88,89]. In summary, the depth of participation in LID governance can be improved through joint governance units comprising communities and departments with decision-making and review authority over seasonal operations and budget adjustments, by leveraging PPGIS and mobile-based reporting workflows to turn resident observations into maintenance tasks and performance indicators; and by institutionalizing the “feedback–adoption–implementation–evaluation” cycle from the TRANSGREEN process into the post-management phase, reinforcing the long-term functionality and social acceptability of LID infrastructure without altering the facts of original case studies [10,25,42,88,110,125].

In LID-guided urban stormwater management, the value and sense of identity cultivated in the early stages of planning can evolve into “shared ownership” and everyday stewardship in the post-management phase. When residents feel they are heard and represented during the planning, design, and construction stages, they are more likely to consistently inspect, clear, and replant LID infrastructure elements, including rain gardens, bioretention strips, permeable pavements, and infiltration trenches. These actions are reinforced by tangible environmental improvements—such as reduced flooding and improved vegetation growth—which build trust in collective efforts and institutional arrangements [26,27]. This embodied sense of ownership has been substantiated in multiple empirical cases. In Quebec, Canada, the micro-regeneration of “green alleys” has demonstrated that, even without direct material incentives, long-term community-based maintenance and environmental education can persist when grounded in local identity, embedding the governance of public spaces into daily community life [119]. Similarly, studies of community gardens in Chinese cities show that cocreation and co-management accumulate significant social capital and mutual trust, establishing a social foundation for the volunteer networks and collaborative capacities required for LID O&M [141]. On a broader scale, Milan’s “BoscoInCittà” illustrates how long-term volunteer planting and environmental education can cultivate cross-sector collaboration networks, demonstrating how shared values can interlink GI, citizens’ daily practices, and urban governance [49,147,148,162]. At the same time, identity-driven observations can become actionable evidence for maintenance through digital and spatial tools. Through spatial tagging of user experiences and environmental concerns, PPGIS practices in Berlin and Turku generate data to set maintenance priorities, guide species replacement, and adjust microtopography. These outputs can be directly integrated into seasonal work plans and GI project performance reviews [42,110]. Research on China’s Sponge City initiative provides quantitative evidence that public understanding of LID concepts and perceived benefits, along with trust in government, significantly enhance satisfaction and willingness to provide ongoing support, underscoring the importance of a positive cycle of contribution, improvement, and pride through identity-driven incentives and transparent feedback mechanisms during post-management [86]. Nevertheless, without institutionalized dialogue and closed-loop feedback, even knowledgeable and financially willing residents may remain restricted to the role of “issue reporters” rather than active cogovernors, limiting the development of stable maintenance commitments and continuous performance improvements [88,89].

In the O&M phase of LID-oriented urban stormwater management, the key to sustaining participation lies in institutionalizing support and incentive mechanisms to prevent

community engagement from diminishing over time [152,156]. When such institutional arrangements are integrated with the routine inspection and light maintenance processes of GI/LID facilities—including rain gardens, bioretention units, permeable pavements, and infiltration trenches—one-off mobilization efforts can become long-term collaborative practices. The foundation of this transformation is a clear delineation of responsibilities, procedural feedback mechanisms, and traceable, closed-loop improvements, which embed public participation in standard operations rather than treating it as a temporary add-on [152]. The long-term participatory governance of the Bratislava Urban Forest Park illustrates how public enthusiasm can become collaborative inertia once citizen engagement is incorporated into formal governance structures and supported by consistent monitoring and feedback systems [153].

From an incentive perspective, organizational behavior studies suggest that clearly structured material, symbolic rewards, leadership endorsement, and cultural signaling can promote sustained pro-environmental behavior through green intrinsic motivation and environmental enthusiasm. Empirical cases, such as the “Green Rewards” program by Kimpton Hotels and the demonstrated Environmental Transformational Leadership (ENTL)-GNIM/GRP-EESB framework, are references for designing composite incentive systems that stabilize participation [154]. In the case of Sponge City, when ecological performance is both perceivable and accompanied by accessible information, public participation and willingness to pay increase significantly. A strong positive correlation between environmental awareness and willingness to pay exists in the Xixian New Area, particularly for improvements in surface water accumulation, reinforcing the “performance and transparency-driven engagement” approach. Studies in six pilot cities found that citizens are willing to contribute financial resources—such as stormwater fees—to maintain green stormwater infrastructure. These findings indicate the feasibility of linking small-scale community funds or stormwater fees directly to the O&M of GI/LID systems [89,94]. In contrast, when institutional responses are inadequate or deliberative processes lack depth, public participation tends to remain procedural rather than substantive, and collaborative efforts in monitoring and maintenance may quickly deteriorate [87,156,163]. In private domains, capacity constraints, such as income level and housing ownership, limit engagement even when risk awareness is high. Thus, policy tools that lower both financial and property-related thresholds are needed to convert latent willingness into sustained action. Moreover, if public preferences are misaligned with planning outcomes, enthusiasm for participation may fade rapidly [3,164]. Taken together, effective O&M of LID infrastructure requires an integrated framework comprising institutional pathways, incentive strategies, capacity and information support, and responsive feedback. Legitimized participation space must be ensured through procedural collaboration and defined responsibilities [32,153]. Turning individuals into collective actors can be achieved via transferable organizational incentives [154]. Consistent investment and trust must be grounded in perceivable ecological performance and transparent communication [94], while participation must be supported by feedback mechanisms that can influence actual decisions to avoid superficial engagement. Only such an approach can enhance infrastructure sustainability and improve hydrological and ecological performance [152]. Finally, Table 4 summarizes evidence on potential, highlighting how institutional incentives, policy frameworks, and supportive organizational structures transform willingness into sustained engagement and durable project outcomes.

Table 4. Case-based evaluation of participation potential.

No.	Case Location	Key Features of Participation Potential	Strengths or Limitations
1	USA (Kimpton Hotels & Restaurants)	Green Rewards program incentivized employees' participation in sustainability (e.g., energy-saving, recycling) through material rewards and organizational support	Successfully boosted employee engagement and environmental behavior; institutional support sustained action [154].
2	China (Hotel Industry)	ENTL enhanced employees' green intrinsic motivation and passion through cultural, leadership, and value-aligned incentives	Mediated by GNIM and GRP; ENTL fostered long-term sustainable behavior among employees [154].
3	China (Xixian New Area)	GI pilot improved residents' awareness and willingness to pay; DCE revealed flood mitigation and ecological value as key drivers	Perceived ecological benefits (notably flood relief and aesthetics) activated potential [94].
4	Bratislava, Slovakia	Bottom-up initiative by NGOs and community activists; included signature collection, public campaigns, broad stakeholder coalition across sectors	Achieved unanimous approval of forest park development conception by City Council; embedded monitoring system ensured institutional sustainability [153].
5	Košice, Slovakia	Citizen-led petition involving over 4,000 signatures; engagement of residents, NGOs, and media; sustained public pressure on municipal authorities	Initially rejected by local authorities; ultimately led to policy reversal and participatory planning of peri-urban forest area development [153].
6	Milan, Italy (BoscoInCittà)	Engagement driven by Italia Nostra and supported by volunteers; residents and civil society groups participated in tree planting, maintenance, and environmental education, creating multiactor networks.	High value recognition motivated continuous participation without reliance on material incentives, strengthening residents' sense of belonging and responsibility for urban forest governance [162].
7	Gothenburg, Sweden	Open design calls incentivized creative contributions from residents and professionals; lowered barriers to engagement	Mobilized latent willingness through market-based incentives; enhanced collective ownership and innovation [32].
8	Multiple European Countries	NBS projects in Germany, Spain, Hungary, Sweden, Netherlands, UK; attempted policy incentives	Weak institutional support; NIMBY effects; lack of continuity in incentive mechanisms [156].
9	Europe (e.g., Sweden, Netherlands)	Community labs and codesign platforms introduced at design and operation stages	Participation intensity dropped at delivery stage due to lack of institutional continuity [32].
10	Phoenix, Arizona, USA	Surveys of private residential GI adoption under climate risk (heat & flood)	Low income, property rights issues, and weak policy incentives limited actual implementation [3].
11	Estonia	10 county-level GI planning cases; public consultations organized by local planning units	Public opinions not integrated; participation remained formalistic; goal mismatch between officials and citizens [163].
12	China (Pilot Sponge Cities)	Surveys showed residents' willingness to pay for LID maintenance and recognition of ecological and social benefits, but long-term participatory platforms and co-management incentives remained weak.	High latent participation potential, yet limited institutional channels risk fading engagement after construction [86,88].

3.3. Limitations and Future Directions

This review of international cases of GI proposes and applies a four-dimensional framework of public participation—breadth, depth, identity, and potential—operationalized through four measurable dimensions: stakeholder diversity, formal decision authority, place attachment/values, and institutional incentives/capacity. Meanwhile, the distribution of these 107 cases within the planning system is uneven. The majority of studies originate from cities in North America and Western Europe, regions that have institutional-

ized participatory planning over decades, while a smaller proportion of cases stem from East Asia, such as rainwater management projects guided by sponge city or LID approaches. By contrast, several cases from the Global South reveal that participatory actions primarily stem from external funding or mandatory requirements imposed by donor-designed urban drainage and climate adaptation projects, rather than longstanding localized participatory procedures followed by local governments. This contextual heterogeneity indicates that our four-dimensional model should be regarded as a configurable template, requiring redefinition according to distinct civic cultures and planning systems.

Several methodological and contextual constraints should be acknowledged. First, the review was restricted to English-language publications. This choice improves comparability across studies but may systematically under-represent GI/LID participation practices reported in other languages or embedded in non-Anglophone planning traditions; participation models from parts of Latin America, francophone Europe/Africa or East/Southeast Asia may therefore be only partially captured. Second, to keep the synthesis focused on participatory GI/LID, we excluded purely technical or modelling papers, conceptual commentaries without empirical cases, and stormwater studies that did not contain a green-infrastructure or participation component. This focus clarifies the comparative patterns, but it also means that some theoretically rich discussions of participation, or studies in which participation was present but not explicitly labelled, are not reflected here. Third, the cases integrated in this review come from heterogeneous participation regimes—long-institutionalized systems in North America and Western Europe, rapidly expanding programme-based initiatives in East Asia, and donor-driven pilots in parts of the Global South. Bringing these experiences into a single four-dimensional framework inevitably flattens context-specific nuances, so the model should be read as pattern-guiding rather than universally prescriptive. Finally, many of the source studies relied on relatively superficial participation indicators (e.g., meeting counts, participant numbers) and underspecified psychological motivations or institutional mediators; while our four-dimensional model offers a functional integration, it necessarily simplifies these more complex social dynamics.

The entire project life cycle—not any single dimension—explains outcomes. Some cases showed clear strengths in ecological/hydrological delivery but simultaneously reported participation-related limitations, especially with respect to distributional equity and community acceptance. We coded these as “mixed (strengths with notable limitations)”, which indicates that outcome assessment in GI/LID is multi-layered. This pattern also points to the role of power and justice in participatory GI. Where participation breadth was narrow or highly professionalized, vulnerable or less vocal groups were either invited late or not empowered to contest site selection and cost/benefit allocation, even though the project as a whole was publicly framed as collaborative [10,14–16,38–43]. In our framework, such inequities become visible through the combined reading of breadth (who entered), depth (who could influence), identity (whose meanings of place were recognized) and potential (whether institutional support actually reduced participation barriers) [10,14–16,38–43,50]. In other words, equity is not an external add-on to participation but is embedded in how these four dimensions are configured. Future applications of the framework could incorporate more systematically disaggregated social data to trace which groups capture the benefits of GI and which bear maintenance or displacement risks. In the planning phase, high stakeholder breadth paired with potential (transparent information, accessible channels) aligns problem framing and site/program choices with local hydrologic and social realities. In the design phase, devolved and verifiable decision authority (depth) along with identity-building codesign (site walks, material trials, microhabitat choices) improves fit-for-place solutions and social acceptance. During construction, institutionalized

breadth (public notices, community liaisons) and rapid feedback loops (depth) prevent quality drift and build trust. In post-management (O&M), identity and potential become binding constraints: transparent role allocation and shared O&M compacts, backed by stable funding, insurance/recognition incentives, and community partnerships, sustain stewardship and protect ecosystem-service reliability. Conversely, where breadth lacks authority, identity is not embedded, or incentives are thin, participation becomes tokenistic and performance decays. Accordingly, institutionalized codesign mechanisms (statutory feedback with duties to respond), complementary equity safeguards to avoid “green gentrification,” and mosaic governance that links neighborhood-scale civic action with citywide standards emerge as stage-specific pathways to better results. The review’s contribution lies in adopting a lifecycle lens and integrating identity and potential alongside breadth and depth to reveal, from a configurational standpoint, the elements that shape success and failure across phases.

Looking ahead, research and practice on GI/LID and participatory governance can be integrated into the “data–mechanism–equity” agenda. With regard to data, cities should build cross-city-comparable, open indicator systems and long-term monitoring networks, using digital twins, PPGIS, and online deliberation platforms to convert public input into traceable spatiotemporal evidence. With regard to mechanisms, quasi-experiments and longitudinal designs should examine the configuration effects of the four participation dimensions, identify the causal chains linking institutional feedback loops, co-management agreements, and incentive design, and explore co-governance and the economics of O&M under blue–green–gray integration. With regard to equity, routine evaluation should incorporate distributive justice and safeguard against green gentrification, establishing decision thresholds and compensation schemes that are more sensitive to vulnerable populations. At the same time, issues of privacy, representativeness, and algorithmic bias raised by digital participation require transparency and ethical norms. Alignment with climate-adaptation finance, pay-for-performance instruments, and community stewardship contracts should be promoted at the policy–finance interface to create replicable, scalable financing loops. In summary, upgrading “participation as input” to “participation as evidence and contract” is prioritized using standardized data and testable configuration pathways—mapped to project phases—enabling transferable prescriptions and verifiable GI governance across institutional settings.

4. Conclusions

This review examines the role of public participation in determining outcomes of urban GI projects, underscoring that how participation is configured matters: relying only on “breadth” (who participates) and “depth” (how decisions are influenced) is insufficient. Our four-dimensional model adds “identity” (community values and place attachment) and “potential” (policy incentives and institutional capacity) to the conventional frame, both grounded in established studies—identity in environmental psychology and community studies [26,27] and potential in participatory governance and institutional analysis [30,33,152]. Throughout the four project phases, these dimensions operate as separate leverage points without repeating phase-specific details: identity shapes problem framing and social acceptance in planning/design, while potential lowers participation frictions through transparency and access; during construction, institutional capacity and incentives sustain oversight and trust; and in post-management (O&M), identity underpins long-term stewardship and potential converts willingness into durable maintenance through funding, liability coverage, and co-management compacts [50,133,156].

Regarding the study’s research questions, we find the following: For RQ1, public participation can be rigorously operationalized with phase-sensitive indicators aligned with

the four dimensions across the GI project cycle. In planning, a stakeholder–diversity index, together with transparency and access scores (potential), measures representativeness and entry barriers. In design, a decision-rights register and design-change traceability (depth) document whether codesign substantively alters specifications. During construction, metrics for issue response and closure times, along with the rate of joint inspections, reflect the integrity of feedback loops (depth and potential). In post-management, stewardship retention, the implementation of co-management agreements, the uptake of incentives and insurance, and the adoption of O&M telemetry quantify whether identity and potential convert willingness into durable maintenance.

For RQ2, performance is the outcome of configurations that vary across phases rather than a single dimension. In planning, combining high breadth and potential—meaning representative access and low participation costs—improves site and program selection and improves equity screening. In design, substantive depth combined with embedded identity leads to fit-for-place solutions and greater social acceptance. In construction, institutionalized breadth, together with timely feedback, reduces quality drift and builds trust. In post-management, identity and potential are decisive, because co-management arrangements, stable funding, and recognition or liability schemes transform prosocial intent into routine care. Conversely, breadth without authority, identity without incentives, or opaque processes tend to yield tokenism and postconstruction performance decay.

For RQ3, we identify practical, phase-appropriate levers to sustain participation. In planning, cities can provide open data portals, convene early design charrettes with explicit duties to respond, and set minimum representativeness thresholds. In design, they can adopt formal codesign protocols linked to earmarked budget windows and maintain public decision logs. In construction, they can publish project dashboards, appoint community liaisons, establish grievance–redress procedures with response and resolution targets, and conduct joint inspections. In post-management, they can formalize co-management compacts, secure multiyear funding and pay-for-performance arrangements, provide insurance and recognition incentives, and integrate PPGIS and telemetry, verifying maintenance evidence. These findings specify boundary conditions—for example, strong institutions coupled with weak community ties or broad consultation without decision power—and motivate context-sensitive configuration of participation within local sociotechnical settings.

Future research should deepen and validate the proposed framework. Large-sample quantitative analyses (e.g., multivariate regression, structural equation modeling, or machine learning) could be used to test the inferred relationships between participation elements and project outcomes. At the same time, causal identification strategies (e.g., natural experiments, propensity-score matching, or instrumental variables) could strengthen causal claims. Longitudinal data collection should track long-term impacts via panel methods or event studies, expanding the scope to cover planning, design, and operations. Equity metrics (e.g., diversity of beneficiary groups, distributional parity) should be incorporated, coupled with GIS and socioeconomic data, to assess heterogeneous impacts and potential redistribution effects. Finally, multi-case comparison and scenario analysis could be used to develop actionable, customized participation guides for different GI types, determine the optimal mix of breadth, depth, identity, and potential, and formulate prescriptive strategies to ensure that good governance produces environmental and social benefits.

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