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Review

The Multifunctional Benefits of Green Infrastructure in Community Development: An Analytical Review Based on 447 Cases

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Abstract: This article describes the relationship between the design features of green infrastructure and the benefits of multifunctionality. To do so, it examines the descriptive linkages between 12 design features and nine benefits using 447 project case studies from the American Society of Landscape Architects. Multiple benefits of green infrastructure were found in 65% of the projects, regardless of the number of applied design features. The major green infrastructure design features with multiple benefits were: bioretention areas, permeable pavements, grassed swales, rainwater harvesting, rain gardens, and curb cuts. The major benefits of applied design features were: enhanced economic capacity, educational opportunities, improvements to the built environment, and enhanced environmental soundness. The findings show that the multiple benefits of green infrastructure's multifunctionality can be inferred in many current cases. Knowing the relationship between design features and their benefits for green infrastructure would facilitate selecting optimal design features to achieve specific goals and planning outcomes. For communities that require a range of complex benefits, a multifunctionality-based green infrastructure will advance highly acceptable climate change adaptation measures.

Keywords: multifunctionality; green infrastructure; ecosystem services; sustainable development; urban planning

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1. Introduction

Green infrastructure (GI) is a planned or managed spatial structure and network of interconnected environmental features, natural areas, open spaces, and landscapes [1–3]. GI has been used to manage rainfall discharge and non-point pollutant sources, which occur due to urban development and increased impermeable layers [1,4–6]. Recently, GI has been a popular concept for planning sustainable land use, and the principle of multifunctionality is its key concept [7–9]. The characteristics of GI's multiple functions have been discussed as a policy measure that can promote sustainable development and smart growth [10–12].

However, there have been some critical discussions concerning the applicability of GI's multifunctionality, which involves employing the limited process of spatial interactions to draw benefits from GI [13,14]. Although a holistic approach is needed to apply GI and obtain the benefits of multifunctionality, some practical applications lack ecological and social perspectives [14–16]. Some studies suggest reasons for this lack of perspective, such as that some stakeholders and policymakers fail to recognize GI, undervalue the various functions and benefits that it provides during the decision-making process [17–19], and lack an understanding of GI's practical applications [1,2].

For these critics, few studies offer a theoretical framework on multifunctionality and the benefits of GI, as well as practical cases or plans with multiple benefits from GI based on multifunctionality. Demuzere et al. analyzed GI's multifunctionality and the co-benefits of mitigation and adaptation in climate change using 86 cases [20]. Science for Environment Policy (SEP) suggested the benefits and costs of GI across multiple cases [11]. Naumann et al. examined the benefits of GI using 121 project cases [2].

This study aims to present GI's multifunctional benefits for local communities by reviewing and analyzing the relationship between the types of community benefits and the design features of GI using multiple cases where GI is applied in communities. This can help provide a broad framework for establishing a green infrastructure plan that reflects the multifunctionality of community benefits. This study adopts a conceptual framework for the comprehensive relationships among the individual benefits of GI, as suggested by previous research. To analyze cases, this study uses data from 447 project case studies collected by the American Society of Landscape Architects (ASLA). Information about GI design features and benefits is gathered by using content analysis; then, the relationships between the benefits of GI's multifunctionality and applied GI design features are analyzed. This study tries to explain which GI design features generate the benefits of multifunctionality and how multiple GI design features are connected to identify the benefits of multifunctionality in the same spatial scope. Finally, this study discusses the limitations and implications for applying GI in urban planning.

2. Literature Review

2.1. Ecosystem Services and GI

Humans receive various benefits from ecosystem services [21–23]. The range of ecosystem services includes provisioning services (which offer natural products such as water and forests), regulating services (which can be considered ecosystem functions such as flood and climate control), cultural services (which offer leisurely, mental, and aesthetic benefits), and support services (which sustain these three main services) [23–25]. Human reliance on ecosystem services is expected to increase over time, yet ecosystems, suffer from sudden social changes, and their services are becoming jeopardized by urbanization [1,17,23]. Shifts in ecosystems can be attributed to social changes such as urban growth; this includes man-made structures and impermeable layers (characteristics of a highly developed society), which are the primary causes of decreasing ecosystem services [17]. Demand for ecosystem services has not been satisfied in urban centers as they are primarily supplied by non-urban green areas, which have seen a decrease in such services due to the abovementioned changes [26].

Recently, policy makers and urban planners have come to regard GI as a tangible measure of sustainable development and climate change adaptation [1]. GI has been proposed as a way to plan and handle the multiple benefits of ecosystem services. The loss of agricultural areas and nature preservation districts, as well as the decline in ecosystem operations, are resulting in a demand for ecological, productive, and cultural functions. In terms of multifunctionality, GI management has potential for ecosystems, and it reveals synergies while acting on semi-natural areas in cities [27]. This means that the various ecological, social, and economic services that ecosystems offer are not mere products of coincidence, but rather ones that GI can clearly administer and provide [1,12,16,24,26].

2.2. The Multifunctionality of GI

The various theoretical discussions of GI's principles have identified two common concepts: connectivity and multifunctionality [9,16,28,29]. Connectivity refers to the network of natural and semi-natural areas with environmental features [11]. Multifunctionality means outputs from multiple ecological, social, and economic functions of GI [12], which derive from combining these functions [30]. Multifunctionality provides benefits for humans (such as improved health and social cohesion) through ecosystem services [22,31]. Various stakeholders and policymakers use the concept of multifunctionality as a key attractive factor of GI planning due to its various functions and benefits in the same spatial area [8,11,32].

Several functions and benefits of GI are connected to ecosystem services, making it possible to enhance biodiversity or environmental functions through green zones [33,34]. This perspective integrates functions and benefits, including social and cultural advantages related to health, well-being, recreation, sports, and a stronger sense of community [13]. Demuzere et al., Lovel and Taylor, Connop et al., and Tzoulas et al. have suggested a theoretical framework for GI's multifunctionality based on an integrated view related to the functions and benefits of ecosystem services [1,20,31,35].

Hansen and Pauleit took a critical stance on the integrated framework of GI's multifunctionality, suggesting that it lacks the operationalization of multifunctionality and has no mediator to link GI's multifunctionality to the benefits of ecosystem services [12]. Madureira and Andresen also criticized the automatic and simplistic relationship between ecosystem services and the benefits of GI's multifunctionality, suggesting there were possible conflicts between ecosystem services and GI's multifunctionality [13].

2.3. The Benefits of GI's Multifunctionality

"Biological structures and processes," which are a functional unit like ecosystems, perform their "functions," which generate "services," and provide the resulting "benefits" to people [14,21,23,24,36]. Land cover changes for projects that employ GI cause shifts in ecosystems and influence functions, services, and benefits [37]. An ecosystem's functions and services are typically classified as ecological, social (including cultural), or economic [1,11,14,21]. This study also discusses the usefulness of GI's multifunctionality in relation to the multiple advantages of ecosystems' functions and services, which are divided into economic, sociocultural, and ecological aspects.

First, the economic benefits will be discussed. When reviving an underdeveloped community, GI can help make it attractive [11,38–40]. Furthermore, GI aids economic growth in target communities (SEP, 2012; Powell et al., 2005; Skipper et al., 2013; TCPA, 2008; USEPA, 2010). Since GI improves communities' social, physical, and environmental conditions, it increases land value [11,32,40–47]. In addition, GI raises productivity and employment opportunities by enhancing working conditions and processes of design and construction through improving the physical environment [11,42,45,46,48]. However, these benefits related to GI's multifunctionality can potentially lead to green gentrification in communities [49]. Green gentrification could displace minority groups and give rise to the unequal distribution of environmental amenities [49]. Applying GI lowers the cost of management by increasing environmental quality through enhancing efficiency in water use, providing opportunities for cooling and heating energy saving, and affording safety from natural disasters [10,11,39–47,50–54]. Many local governments that have recognized GI's benefits have started deregulating and offering incentives to promote it [41,43,44].

Next come the benefits of GI's multifunctionality from the sociocultural angle. GI promotes leisure activities and creates aesthetics in communities, in addition to offering advantages regarding nature's educational role and preserving historical natural resources [1,10,32,38–40,42,45,46,55]. Green zones expanded by applying GI and regenerating communities improve the accessibility of public services, provide safety by preventing crime and natural disasters, enhance communities' physical environments, and boost psychological, mental, and physical health [10,31,38–40,42,43,45,46,51,52]. GI empowers residents to manage resources by themselves so they can improve the environment, which leads to an adaptive learning process where people can acquire knowledge to maximize ecosystem services [1]. This induces resident participation, which strengthens the network, promotes a sense of attachment to a location and social cohesiveness, and creates regional harmony [1,38,41,45,46,50,52,55,56]. Participation also implies that the community can create sustainable environments in establishing environmental justice, as well as the inclusion of community members [57].

Lastly, the benefits will be discussed from the perspective of ecology. The benefits of ecosystem functions are based on discussions of rainfall effluence and flood control, and include reducing non-point pollutant sources that result from decreased rainfall effluence [5,10,32,38–42,44–46,48,50,52,55,58–60]. Diminishing rainfall effluence and non-point pollutant sources offers benefits by protecting a region's ecosystems and maintaining water circulation. By providing cities with green areas, GI adapts to and alleviates climate change impact through cooling; in addition, GI protects biological diversity and habitats, contributes to ecological networks, improves the environmental quality of land, water, and the atmosphere, enhances microclimates, and reduces carbon emissions [1,10,32,38,39,41,42,44–52,55,61].

2.4. A Conceptual Framework for GI's Multifunctionality

GI's multifunctionality combines its individual operations to create economic, sociocultural, and ecological advantages. The aggregation of these benefits produces a synergistic effect that exceeds the sum of its individual merits [1,8,61]. GI's individual design features cannot necessarily deliver all the desired perks, but if individual design features are interlinked, most of the aforementioned benefits can be provided [16].

In this study, GI's multifunctionality defines the tangible and intangible outputs from the ecosystem services according to the integrated view provided in the previous theoretical discussion. Despite some criticisms of the process leading from functions to benefits, the main part of GI's biophysical structure remains ambiguous, like a black box. Thus, by adopting an integrated perspective, this study divides GI's multifunctionality into economic, sociocultural, and ecological aspects based on ecosystem services.

Figure 1 depicts this study's framework, which is based on Hansen and Pauleit's description of the steps that lead from functions to benefits [12]. This framework classifies GI services into economic, sociocultural, and ecological elements, and links each service to its specific potential benefits for human well-being. Three GI functions are related to ecosystem services in the integrated view of GI's multifunctionality and ecosystem services. Economic functionality provides a basis for promoting economic activity and refers to enhancing economic capacity, which can reduce costs and increase employment, as well as indirect productivity. Sociocultural functionality refers to general sociocultural matters that can change directly and indirectly through GI. It includes educational opportunities, improvements to the built environment, an increase in social capital, improved landscape aesthetics, and the foundation for sustainable development. Ecological functionality refers to GI's ecological and environmental operations. It includes runoff control, pollution control, preservation, reducing carbon dioxide emissions, other enhancements in environmental soundness, and climate change adaptation. Table 1 shows the specific benefits of GI's multifunctionality.

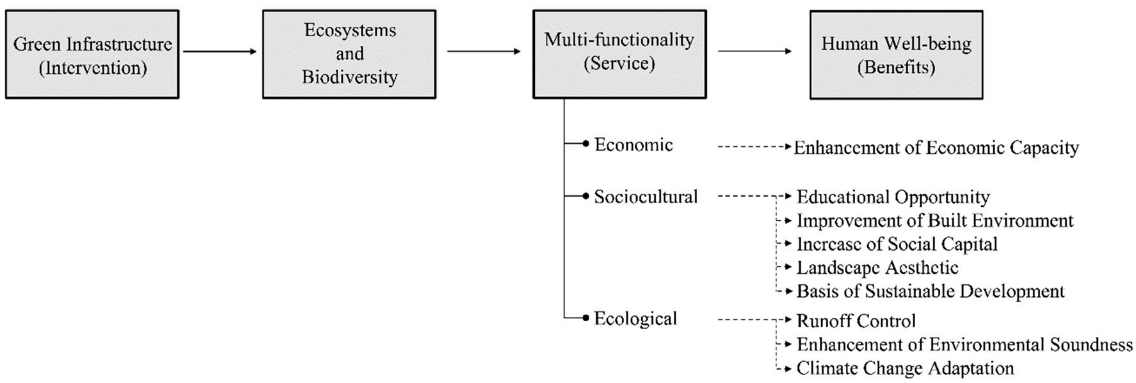

Figure 1. The conceptual framework of GI's multifunctionality and benefits. Note: Adapted from Hansen and Pauleit [12].

Table 1. Multifunctionality of GI and types of community benefits.

Functionality	Type of Benefit	Description
Economic	Enhanced economic capacity	- Local economic development with community benefits and promotion of vital urban centers - Improved marketability - Increased retail sales - Increased property values and tax revenue - Tax/fee credits and other financial incentives - Reduced costs associated with infrastructure, development, flooding, water treatment, and healthcare - Reduced use of energy (for cooling), salt (for icy roads), and water - Urban agriculture/sustainable food production - Increased worker productivity among office employees - Green job creation
Sociocultural	Educational opportunities	- Increased recreational opportunities and interactions with nature - Cultivation of public education opportunities (regular exposure to nature and increased awareness of environmental issues)
	Improvement of the built environment	- Improved access to public services, such as available water supply and green spaces - Reduced noise pollution - Improved housing quality
	Increase in social capital	- Enhanced quality of life and public participation - Community development and stronger community cohesion - Opportunities for youth to spend time in public spaces - More social gathering spaces - Less crime - Cultural expression - Increased physical/mental health
	Landscape aesthetics	- Improved aesthetics - Expanded landscape and townscape benefits - Visual screening of unsightly buildings or infrastructure - Landscape restoration
	Basis of sustainable development	- Regulatory compliance credits - A high-quality environment to attract and retain a competent workforce - Links between towns and the countryside - Non-motorized transport systems (such as cycling lanes, footpaths, and combined routes) - Regeneration of degraded sites for new, high-quality development - Efficient land use
Ecological	Runoff control	- Reduced downstream erosion - Flood control/prevention, storm surge protection, and accommodation of natural hazards - Better management of stormwater runoff - Fewer incidents of combined sewer overflows - Maintenance of predevelopment runoff volumes and discharge rates
	Enhanced environmental soundness	- Improved groundwater recharge and drinking water - Preservation of terrestrial and aquatic habitats - Improved water quality and conservation - Improved air quality and less carbon dioxide in the atmosphere - Biodiversity protection and pollination - Protection to enhance geologically important sites, such as nature preserves and heritage sites - A reduced ecological footprint - Improved pollutant loadings
	Climate change adaptation	- Reduced gray infrastructure needs - Reduced urban heat islands and ambient temperatures - Resilient infrastructure and climate change adaptation/mitigation

Sources: Cirillo and Podolsky, Skipper et al., Clements, Juliana, and Davis, CNT, Dietz, Dietz and Clausen, EEA, Entrix, SEP, Foster, Lowe, and Winkelman, HBC, HUD, LID Center, Powell et al., Lovell and Taylor, MMSD, the Scottish Government, Odom, TCPA, USEPA, Zimmer et al., Zimmerman et al., Ziogou et al., Hendricks et al., Ran and Tang, Wan, Shen and Choi, Xiao et al., Van Mechelen, Dutoit and Hermy [1,5,10,11,18,32,38–46,48–59,61].

3. Materials and Methods

This study used data from the project case studies collected by ASLA [62] at the request of the United States Environmental Protection Agency, which wished to collect information on rainfall effluence management. Using an online survey (https://www.surveymonkey.com/r/WCVCNHZ) [63], more than 300 ASLA members and participants investigated 479 project cases that applied GI from 43 U.S. states, the District of Columbia, and Canada.

There are 23 questions in the survey. Besides basic GI project information, such as the respondent's organization, project name, location, and designer, the survey consists of 10 multiple choice questions (project type and cost, impervious surface area, preserved green area, and GI installation method) and 10 descriptive questions (a short description of the project, the project's benefits, and a cost comparison with the existing development method). ASLA case reports are largely comprised of project specifications, a cost and job analysis, and performance measures, as detailed in Table 2. Each case is based on responses to 17 survey questions; some cases include project recognition and additional information. Depending on its characteristics, each survey question has been classified as categorical data, the project's actual quantitative data, or the respondent's unstructured, descriptive data. The final number of case studies used for this research was 447 after 32 project cases were excluded. These were overlapping project case reports or reports with incomplete information. ASLA's project case studies were collected from its official website (https://www.asla.org/stormwatercasestudies.aspx) [62].

Table 2. Survey of ASLA and data characteristics.

Items	Answer Type		Variable (Table 3)
	Multiple Choice	Description	
Project Specifications			
· General information and project description		○	
· Project type	○		a. f.
· Design features	○		e.
· Specific requirement or mandates	○		
· Managed impervious area	○		
· Amount of existing green/open space conserved or preserved to manage stormwater on site	○		c.
· Regulatory environment and regulator	○		
· Considering the client's request such as energy savings, usable green space, or property value enhancement		○	
Cost and Job analysis			
· The estimated cost of the stormwater project	○		d.
· Performing cost analysis (green vs. gray)	○	○	
· The cost impact of conserving green/open space on the overall costs of the site design/development project	○	○	
· The cost impact of conserving green/open space for stormwater management in comparison with traditional site design/site development approaches (gray infrastructure)	○	○	
· Number of jobs created		○	
· Job hours devoted to the project		○	
Performance Measures			
· Stormwater reduction performance analysis	○	○	b.
· Community and economic benefits resulting from the project	○	○	b.

Sources: The items and answer type were obtained from https://www.surveymonkey.com/r/WCVCNHZ [63].

This study conducted content analysis to extract, quantify, and analyze information on the benefits in a GI case report containing descriptive questions. The content analysis systematically and objectively identifies and infers the specific characteristics of a message [64–66]. This study extracted data according to the following six steps, based on the work of Prasad [66]:

1. Formulation of the research question and goal;
2. Selecting content and sample;
3. Developing content categories;

4. Finalizing the unit of analysis;
5. Coding and checking inter-coder reliabilities;
6. Analyzing the collected data.

As a first step, this study had two research questions: (1) How many GI features are linked in the same area to produce multiple benefits? (2) Which GI design features provide multifunctional benefits? By solving these questions, this study can help identify the multifunctionality of GI's community benefits and explains how these benefits differ depending on the type of business and the individual green infrastructure elements applied. Second, we selected content and sample of the analysis, which involves a case study report of 447 GI applications by ASLA. Third, we created the content categories shown in Table 3. Table 3 is based on the research questions, the multifunctionality of GI, the type of community benefits (Table 1), and the ASLA questionnaire (Table 2). The fourth step involves finalizing the unit of analysis. The unit of analysis is the minimum unit of coding, which requires allocating the unit of analysis to the content category and differs depending on the nature of the data and the purpose of the study [66]. In the case of quantitative data provided by case reports (estimated project costs and the amount of green space available for managing stormwater) and categorical data (type of facility and design features), they allocated to the categories by designating the categories themselves as the unit of analysis. However, a new unit of analysis was needed to allocate information on benefits, which involves descriptive data, to the category called "types of benefits." The types of units are divided into recording and context units. In the case of using a recording unit—such as a single word (e.g., rainfall runoff, education, and flood)—as a unit of analysis, it is difficult to deduce meaning by only relying on the occurrence frequency of the selected word [66]. In this study, a description of the types of community benefits derived from the theoretical review (Table 1) was used as the context unit, which is a larger unit containing the features of the recording unit [66]. Table 1 was also used as a coding checklist in the coding phase.

Table 3. Variables and classifications from the 447 cases.

Variable	Classification	Variable	Classification
a. Type of facility	a1. Institutional/educational, government complexes, public facilities a2. Open spaces, parks, gardens a3. Transportation corridors, streetscapes, parking lots a4. Mixed use a5. Industrial use a6. Commercial use a7. Residential use	d. Estimated project cost	d1. USD 100,000 or less d2. USD 100,000–USD 500,000 d3. USD 500,000–USD 1,000,000 d4. USD 1,000,000 or more
b. Type of benefit	b1. Enhanced economic capacity b2. Educational opportunities b3. Improvement of the built environment b4. Increase in social capital b5. Landscape aesthetics b6. Basis of sustainable development b7. Runoff control b8. Enhanced environmental soundness b9. Climate change adaptation	e. Design features	e1. Bioretention area e2. Constructed stormwater wetlands e3. Permeable pavements e4. Grassed swales e5. Grassed filter strips e6. Rainwater harvesting e7. Green roofs e8. Riparian buffers e9. Rain gardens e10. Curb cuts e11. Disconnected downspouts e12. Other
c. Amount of green spaces for managing stormwater	c1. 0.047 ha or less c2. 0.047 ha–0.405 ha c3. 0.405 ha–2.023 ha c4. 2.023 ha or more	f. Project type	f1. Part of a new development f2. Part of a redevelopment project f3. A retrofit of an existing property

The fifth step is coding and checking inter-coder reliabilities. First, in the case of coding, 10 urban planning and green infrastructure experts used the coding checklist described in Table 1 to review reports. Then, they classified the benefits associated with each case. There are two approaches to content analysis: quantitative and qualitative, depending on how the text unit is categorized in the coding phase. The quantitative technique, with mutually exclusive categories, has limitations for assigning specific texts to a single category, whereas the qualitative method is capable of assigning text units to more than one category at the same time [67]. For this reason, this study employed a qualitative approach. Inter-coder reliabilities are then checked. This step ensures that the coding results are consistent between the coders and it is also a more important step in content analysis when a human—rather than a computer—participates as a coder [68]. In this study, to increase the reliability between coders, 10 expert coders collectively calculated the frequency of the benefits and synthesized them. After verifying the first round of classification results and identifying 53 cases that had been classified inconsistently, the same experts re-analyzed the results for those cases, so that consistent classification results could be derived from the process. Lastly, exploratory data analysis (EDA) was used in the data analysis stage. EDA is useful for pinpointing patterns of overall data and then setting and adjusting hypotheses to solve problems [69,70]. This study used cross-tabulation to perform the following analysis, which is one of the non-graphical methods of EDA, based on the frequency of occurrence of the unit.

The number of suggested benefits and GI design features in the project case reports were counted to understand the relationships between GI design features and the advantages of multifunctionality. The ratio of cases with more than two GI benefits was used to identify multiple merits based on GI's multifunctionality.

By multiplying the number of GI design features and related benefits, it was possible to ensure that individual GI design features were related to all of the benefits in the case reports. This means that if several GI design features and benefits of multifunctionality existed simultaneously in the same project case report, the number of advantages counted overlapped with all possible design features. For example, if a specific report suggested a green roof and rain garden as applied design features, and there was an increase of social capital and improvement of the built environment, the relationship between GI features and benefits counted for a total of four connections considering all possible relationships. These include green roof increases in social capital, green roof improvements of the built environment, rain garden increases in social capital, and rain garden improvements of the built environment.

In some cases, we multiplied the number of GI design features and related benefits to determine the relationships between design features and benefits, for two reasons. First, in each case, GI's multifunctionality benefits emerge when all the applied GI design features are connected. From a holistic angle, GI's multifunctionality depends on the linking of design features; this connectivity helps to produce the overall advantages. Although the limited data make it impossible to measure each design feature's contribution to the overall benefits, it is worth considering the role of connectivity. Second, benefits are based on GI's multifunctionality. Benefits for human well-being cannot be produced by a single factor. To consider all possible ways in which GI design features and benefits are connected, this study multiplied the number of GI design features by the related number of benefits. The findings suggest the types of GI design features that generally lead to each kind of benefit.

4. Results

4.1. Descriptive Analysis of the 447 Project Cases

Figure 2 shows the results of the descriptive analyses based on the 447 project cases. The most common type of facilities were: institutional/educational, government complexes, and public facilities (33% of all cases, a1); next came open spaces, parks, and gardens (28%, a2), followed by transportation corridors, streetscapes, and parking lots (14%, a3). Regarding benefits, enhanced economic capacity and improvements to the built environment (b3) were the highest at 18% each, followed by enhanced environmental soundness (14%, b8) and educational opportunities (11%, b2). The projects had green spaces for purposes of managing stormwater that ranged from 0.047 ha to 0.405 ha (25%, c2) to less than 0.047 ha (24%, c1) or 0.405–2.023 ha (22%, c3), and more than 2.023 ha (20%, c4). In terms of estimated project costs, most projects ranged from USD100,000 to 500,000 (33%, d2), 27% cost less than USD100,000 (d1), and 25% cost at least USD1,000,000 (d4). The most frequently used design features were grassed swales (18%, c4), rain gardens (15%, c9), permeable pavements (15%, e9), and bioretention areas (14%, e1). For project type, "retrofit of existing property" comprised more than half of all cases (53%, f3).

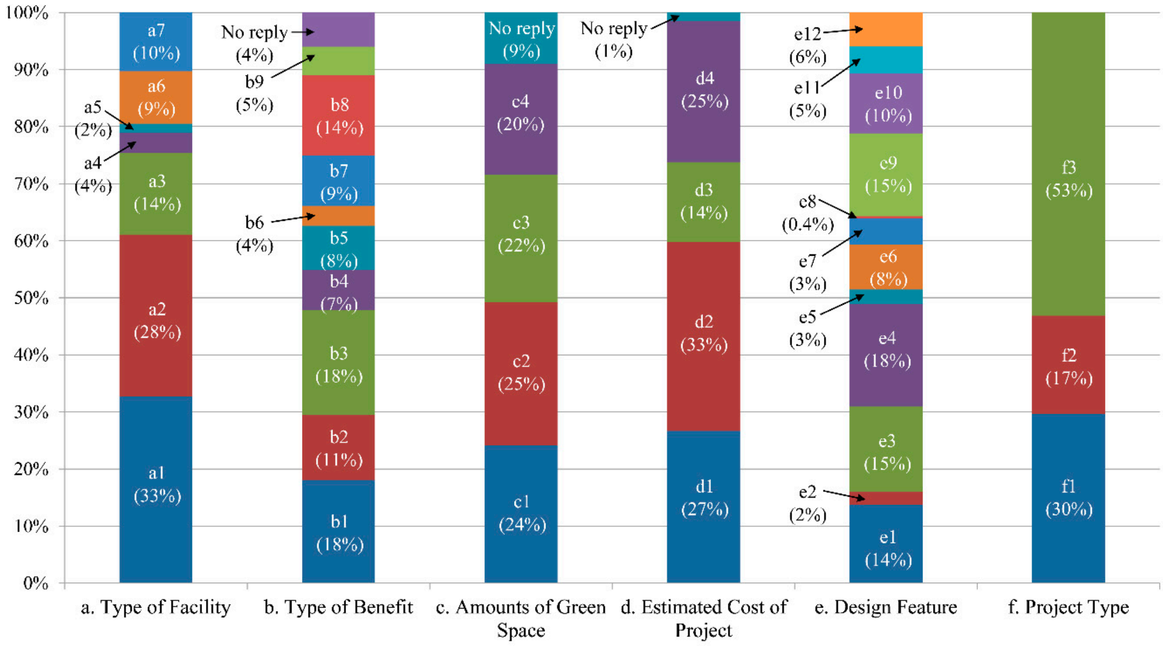

Figure 2. Summary of the 447 cases. Note: The classification on each bar is the same as the classification in Table 3.

4.2. Applied Design Features and the Multiple Benefits of GI

Before analyzing the relationships between design features and benefits, we explored how individual design features and benefits appear in projects. The design features most commonly used in the 447 cases, as well as the facility types and project types, were examined (see Table 4). A total of 1,518 design features were applied in the 447 cases. The numbers in Table 4 indicate the reported total number of each type (e.g., the number between a1 and e1, 63, is the reported number of e1 design features—bioretention areas—in cases of a1-type facilities, i.e., institutional/educational, government complexes, public facilities). The average number of applied GI design features was 3.4. Among the 11 GI design features that were applied, 80% consisted of bioretention areas, permeable pavements, grassed swales, rain gardens, curb cuts, and rainwater harvesting. When sorted by type of facility, the facilities that used the most design features were institutional/educational, government complexes, and public facilities. Although many design features were employed with regard to the type of facility, there was no significant difference between the average numbers of design features applied to a single project, as they ranged from three to five.

Table 4. Multiple applied design features (types of facilities and project types).

Design Feature	Type of Facility							Project Type			Total
	a1	**a2**	**a3**	**a4**	**a5**	**a6**	**a7**	**f1**	**f2**	**f3**	
e1	63	55	35	9	3	22	21	60	41	107	208
e2	5	18	1	2	1	6	2	17	5	13	35
e3	80	47	34	12	5	20	29	56	60	111	227
e4	85	89	28	11	6	27	26	88	52	132	272
e5	14	9	3	4	0	2	7	15	9	15	39
e6	49	32	6	9	3	8	13	26	23	71	120
e7	34	8	3	4	1	10	9	21	17	31	69
e8	-	3	3	-	-	-	-	-	-	6	6
e9	84	48	24	10	5	26	24	64	50	107	221
e10	49	34	35	6	2	19	14	52	36	71	159
e11	28	11	6	7	3	7	10	23	10	39	72
e12	30	25	16	6	2	4	7	18	21	51	90
Total number of design features	521	379	194	80	31	151	162	440	324	754	1518
Total number of project cases	146	127	64	16	7	41	46	132	77	237	447
Average number of applied design features of each project case	3.6	3.0	3.0	5.0	4.4	3.7	3.5	3.3	4.2	3.2	3.4

Note: The classifications of e1–e12, a1–a7, and f1–f3 are the same as the classifications in Table 3.

Table 5 shows the multiple benefits of GI. There were 964 total benefits in the 447 projects, which were divided into nine types. Of these, five comprised 76% of the total: enhanced economic capacity (b1), educational opportunities (b2), improvement of the built environment (b3), runoff control (b7), and enhanced environmental soundness (b8). On average, a single project case had 2.2 benefits. When considering the "type of facility" (as defined in Table 3, a1–a7), "open spaces, parks, and gardens" (a2) produced the most common advantages. The average was 2–2.4 benefits (excluding industrial type, which was an outlier, with only 1.3 benefits). When sorted by "project type" (as defined in Table 3, f1–f3), "retrofit of existing property" (f3) produced the fewest benefits and averaged less than one benefit. This reflects the fact that the benefits were not documented in some retrofit cases where the GI design feature was applied in a limited way to a very small area. "Part of new development" (f1) and "part of a redevelopment project" (f2) averaged 4.0 and 3.4 benefits, respectively. These results reveal a large difference in the number of advantages compared to the average number of design features applied to the retrofit type, as shown in Table 4.

Table 5. Multiple benefits of GI (type of facilities and project types).

Type of Benefit	Type of Facility							Project Type			Total
	a1	**a2**	**a3**	**a4**	**a5**	**a6**	**a7**	**f1**	**f2**	**f3**	
b1	37	63	18	13	1	20	26	85	55	38	178
b2	53	30	10	4	2	5	7	68	27	16	111
b3	45	61	58	6	2	14	14	115	41	44	200
b4	26	19	10	2	1	3	5	34	14	18	66
b5	27	18	16	1	1	12	5	55	16	9	80
b6	12	6	3	1	–	6	2	11	10	9	30
b7	28	31	16	5	–	8	12	64	26	10	100
b8	44	62	9	4	2	9	18	76	49	23	148
b9	16	15	6	–	–	8	6	19	21	11	51
Total number of benefits	288	305	146	36	9	85	95	527	259	178	964
Total number of project cases	146	127	64	16	7	41	46	132	77	237	447
Average number of benefits per project case	2.0	2.4	2.3	2.3	1.3	2.1	2.1	4.0	3.4	0.8	2.2

Note: The classifications of a1–a7, b1-b9, and f1–f3 are the same as the classifications in Table 3.

4.3. Multifunctional Benefits of GI Design Features

As previously discussed, the "benefits of GI's multifunctionality" means that several benefits occur in the same space due to GI design features. Various merits result from the ecosystem services provided by GI. In this study, GI features could provide at least two benefits, given the operational range of several benefits. The relationships between GI design features and multiple benefits were examined using the synthesized data from the 447 project cases.

Tables 6 and 7 show the number of benefits and design features that were connected and applied to identical spaces based on type of facility and project type. Looking at the number of design features by type of facility, 70 of the 447 cases utilized one design feature, and 377 employed at least two. There were 291 cases with at least two benefits in each case. The ratios of cases with multiple benefits from GI's multifunctionality ranged from 43% to 71% for each type of facility and were at least 62% when industrial type was excluded. When exploring the number of design features and resulting benefits based on project type, the ratio of cases with multiple benefits from GI's multifunctionality ranged from 61% to 68%. In the "retrofit of an existing property" type, although the total number of benefits was low, the multiple benefits were relatively high.

Table 6. Number of design features and benefit types as the criteria for the type of facility.

Type of Facility	Number of Applied Design Features									Number of Benefit Types								Ratio of Cases with Multiple Benefits
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	None	
a1	22	29	24	24	22	15	7	3	-	29	43	27	15	5	-	1	26	62%
a2	23	43	19	19	10	7	3	3	-	20	28	30	24	6	1	1	17	71%
a3	10	15	18	12	4	4	-	1	-	12	20	7	4	9	2	-	10	66%
a4	1	4	-	-	2	4	4	-	1	5	5	2	1	1	1	-	1	63%
a5	-	1	2	1	2	-	-	-	1	1	1	2	-	-	-	-	3	43%
a6	6	3	10	11	6	2	2	-	1	11	12	9	3	1	1	-	4	63%
a7	8	4	12	9	6	5	2	-	-	11	15	6	5	2	1	-	6	63%
Total	70	99	85	76	52	37	18	7	3	89	124	83	52	24	6	2	67	

Note: The classifications of a1–a7 are the same as the classifications in Table 3.

Table 7. Number of design features and benefit types as the criteria for project type.

Project Type	Number of Applied Design Features									Number of Benefits								Ratio of Cases with Multiple Benefits
	1	2	3	4	5	6	7	8	9	1	2	3	4	5	6	7	None	
f1	31	19	23	23	16	13	4	3	-	44	66	41	34	16	2	-	35	67%
f2	3	14	16	8	16	10	8	1	1	33	42	22	9	3	3	1	19	61%
f3	36	66	46	45	20	14	6	3	2	12	16	20	9	5	1	1	13	68%
Total	70	99	85	76	52	37	18	7	3	89	124	83	52	24	6	2	67	

Note: The classifications of f1–f3 are the same as the classifications in Table 3.

Table 8 shows how many benefits could be provided according to the number of applied GI features. A total of 65% of the 447 projects had at least two benefits, 15% had none, and 20% had only one, regardless of multiple GI design features. Among the single design features employed in the projects, 63% had at least two GI benefits. For more than two design features, the ratio of the cases with multiple benefits from GI's multifunctionality was between 63% and 69%.

Table 8. Relationship between the number of applied design features and the number of benefits.

Number of Design Features	Number of Benefits								Ratio of Cases with Multiple Benefits
	1	2	3	4	5	6	7	None	
1	14	21	10	8	3	1	1	12	63%
2	16	21	19	17	5	-	-	21	63%
3	19	29	12	7	4	2	1	11	65%
4	20	23	11	10	4	1	-	7	64%
Above 5	20	30	31	10	8	2	-	16	69%
Total	89	124	83	52	24	6	2	67	

Table 9 shows the GI design features that provide benefits based on their multifunctionality. Considering the overlapping relationship between GI design features and benefits, the number of advantages was 3,329. The 6 types of GI features (except for others), such as bioretention areas (e1), permeable pavements (e3), grassed swales (e4), rainwater harvesting (e6), rain gardens (e6), and curb cuts (e10), made up 78% of all benefits provided in the synthesized project cases. For almost all GI features, most benefits took the form of enhanced economic capacity (b1), more educational opportunities (b2), improvements to the built environment (b3), landscape aesthetics (b5), runoff control (b7), and enhanced environmental soundness (b8). Except for riparian buffers (e8), all GI design features were associated with every kind of benefit based on multifunctionality. The characteristics of benefits with a high correlation to GI design features were more tangible. However, the existence of intangible benefits may also be inferred. These benefits may be social capital (b4), landscape aesthetics (b5), climate change adaptation (b9), and the basis of sustainable development (b6). Although the riparian buffer (e8) is linked to multifunctional benefits such as more educational opportunities (b2), improvements to the built environment (b3), landscape aesthetics (b5), and runoff control (b7), the data in this study revealed very few cases (only six cases) in which the buffer had been applied. It was therefore difficult to determine likely outcomes.

Table 9. The relationship between the type of applied design feature and the type of community benefit.

Design Feature	Type of Benefit										Total
	b1	b2	b3	b4	b5	b6	b7	b8	b9	None	
e1	79	62	97	38	38	15	44	61	22	29	456
e2	21	10	16	9	5	4	10	9	6	2	90
e3	99	62	100	33	39	21	47	58	24	34	483
e4	111	72	113	36	47	24	55	105	31	41	594
e5	15	9	19	6	9	4	7	15	4	6	88
e6	67	30	47	21	21	6	25	54	15	12	286
e7	27	21	27	15	9	8	11	27	7	10	152
e8	2	3	9	-	3	-	3	1	-	-	21
e9	88	55	70	45	43	15	33	74	26	39	449
e10	49	39	80	26	28	15	32	45	27	23	341
e11	42	21	15	6	9	5	16	14	5	11	133
e12	40	20	56	15	23	8	28	35	11	5	236

Note: The classifications of b1-b9 and e1–e12 are the same as the classifications in Table 3.

5. Conclusions and Implications

This study showed GI's multifunctional benefits for local communities through a review and exploratory analysis based on 447 cases. Regarding the conceptual framework adopted from previous studies, this study offers qualitative evidence for how GI's multifunctionality provides multiple benefits for communities.

In the 447 project cases, the average number of applied GI design features was 3.4, and the average number of GI benefits was 2.2. The six most frequent design features were: bioretention areas, permeable pavements, grassed swales, rain gardens, curb cuts, and rainwater harvesting. The five most common benefits were: enhanced economic capacity, educational opportunities, improvement of the built environment, runoff control, and enhanced environmental soundness. As for the type of facility, open spaces, parks, and gardens had a high ratio of multiple benefits per project (as high as 71%), while the industrial use type had a low ratio of multiple benefits per project (43%). For other types of facilities, the ratios of multiple benefits were between 62% and 66%.

To understand the relationship between GI's connectivity and multifunctionality, several GI design features with multiple benefits were suggested. In one GI design feature, 63% of cases had multiple benefits (more than two) based on multifunctionality. However, the benefits of GI's multifunctionality must not increase as the number of applied GI features rises. The findings of this study showed that similar trends of multiple benefits exist regardless of the number of applied design features.

Most benefits took the form of enhanced economic capacity, educational opportunities, improvements to the built environment, and enhanced environmental soundness. The GI design features utilized to produce multiple benefits were bioretention areas, permeable pavements, grassed swales, rainwater harvesting, rain gardens, and curb cuts.

Some limitations of this study should be acknowledged. First, the data contained in the case reports were limited. The identified benefits of GI's multifunctionality were based on the advantages described by experts for each of the 447 cases. Thus, some bias on the part of the experts should be considered, which may have affected which benefits were selected. Although this study tried to diminish this type of bias by using numerous case studies, this approach does not represent a statistically significant method. The issue could be resolved if data documenting the benefits were collected using stricter standards. This would involve asking questions to determine the purpose of, and intention behind, the decision to apply GI, as well as by investigating situations that produce benefits in GI-applied cases. If the benefits associated with purpose and intention are distinguished from the overall and indirect benefits of a case, it should be possible to more clearly identify the stages at which multifunctionality appears as a consequence of GI design features. By analyzing specific situations in which benefits arise, researchers can determine the optimal conditions for applying GI design features.

Second, there is no precise mechanism, either in theory or in practice that can directly link a GI design feature to specific multifunctional benefits. This study pinpointed and theoretically discussed the connectivity between various multifunctional benefits and GI design features. By multiplying the number of GI design features by the number of their related benefits for specific areas, this study analyzed the overall patterns in these cases. However, it is not yet possible to determine which GI design practices can be optimally combined to produce the maximum benefits, or how each GI design feature is linked, in a direct and statistically significant way with a particular type of multifunctional benefit. This limitation could be overcome by collecting more findings and using more diverse research methods to determine and measure how ecosystem service benefits are applied to various GI design features. The method used to estimate ecosystem service benefits provides monetized benefit results; if such merits are calculated in a case with GI design features, that method could be used to analyze the advantages and input costs, estimate the maximized benefits, and predict its feasibility.

Third, the size and networked characteristics of GI design features were not considered. GI design features exhibit a range of sizes and networked structures. The networked structures or connectivity of these features are as varied as the sizes of the applied spaces and the design features. However, this problem is difficult to solve because of the different characteristics of the numerous cases that were examined. For this reason, this study used the number of GI design features to determine connectivity, under the assumption that more than two design features were included in a case if GI's connectivity or networks existed in the same spatial area. Although this study employs an assumption, this limitation will be resolved once theoretical discussions have been advanced, and empirical cases of GI network structures and connectivity have accumulated. It is important to identify how GI design features are connected to each other and to the existing urban infrastructure in GI-applied projects. This information can be derived from empirical cases. Examining various combinations of design features will help to clarify multifunctional structures that can create a synergistic effect.

Despite the limitations of the exploratory analysis, this study has some implications for stakeholders and planners of GI and sustainable development. First, GI planning was discussed as a holistic approach to sustainable development. This means that all aspects of planning should consider green zones, open sites, and natural areas as interconnected systems in space so that their multiple benefits or ecosystem services can be attained. However, some stakeholders or planners doubt their benefits or ecosystem services due to intangible factors such as social capital, aesthetics, and sustainability. This study has presented inferred evidence from various cases on the multiple benefits of GI design features, including intangible benefits. Although the estimation of intangible benefits was not measured directly, the relationships between GI design features and benefits provided some basic information for stakeholders and planners to use in a holistic approach to GI planning. These findings could be used to plan interventions to realize the intended benefits of GI and explore ways in which GI design features could be applied. The data regarding the benefits of GI in this study were as perceived by experts. These perceived benefits might not clearly reflect the social contexts of communities, which could potentially affect the benefits of GI. With additional data about the social contexts of communities, the relationship between GI benefits and social contexts can be more clearly understood. In addition, with detailed quantitative data on the composition and cost of each GI application, a statistical analysis could be performed to determine the differences in benefits according to GI composition and certain trends.

Second, despite being a topic that has long been discussed in urban planning, sustainable development has been constrained from a methodological angle. It has been challenging to find an alternative to urban planning and design, starting from a definition of sustainable infrastructure (compared to existing infrastructure) and going all the way to questions of the effect on sustainability. As for climate change, sustainable development includes adapting to its impacts. GI's principles and design features and the benefits of multifunctionality are highlighted as an alternative to policy measures, including the co-benefits of adaptation to, and the mitigation of, climate change. The results of this study also underscore the role and potential of GI in mediating between policy problems of climate change and solutions in which GI design features relate to functions and benefits such as runoff control, urban heat islands, energy savings, air quality, and water quality. The results suggest that GI can be used as an adaptive measure when a community establishes a plan for accommodating climate change. Most community residents want climate change adaptations to be linked to their community's socioeconomic development; GI's multifunctionality could serve as a model for pursuing the multiple benefits of an adaptive measure at the same time. Notably, if GI's economic and sociocultural benefits are connected with the needs of residents, any adaptive measures will be more acceptable to residents and stakeholders.

Lastly, the 447 cases in this study were bounded by some limited geographical contexts, such as 43 U.S. states, the District of Columbia, and Canada. When applying GI to specific communities, planners should consider the environmental and socioeconomic conditions of those communities. Regarding environmental conditions, microclimates and vegetation should be considered. Recently, GI has been adopted as a policy measure for climate change adaptation in urban planning, but the benefits and effects of GI have varied according to specific environmental conditions. In particular, rainfall patterns, soil types, and vegetation types should be considered as part of the geographical contexts of communities. Regarding socioeconomic conditions, green gentrification should be considered. The various benefits of GI will indirectly improve communities' built environments and ecosystem services. However, such improvements could have adverse effects, such as displacement and environmental inequality, for some disadvantaged groups. As such, there is a need for planning in coordination with communities when applying GI.

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