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Review

Approaches to Multi-Objective Optimization and Assessment of Green Infrastructure and Their Multi-Functional Effectiveness: A Review

Jia Wang [1], Jiahong Liu [1,2,3,*], Hao Wang [1] and Chao Mei [1]

1 China Institute of Water Resources and Hydropower Research, State Key Laboratory of Simulation and Regulation of Water Cycle in River Basin, Beijing 100038, China; jiawang531@163.com (J.W.); wanghao@iwhr.com (H.W.); meichao@iwhr.com (C.M.)
2 School of Transportation and Civil Engineering & Architecture, Foshan University, Foshan 528000, China
3 Engineering and Technology Research Center for Water Resources and Hydroecology, Ministry of Water Resources, Beijing 100038, China
* Correspondence: liujh@iwhr.com

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Abstract: Green infrastructure (GI) is a contemporary area of research worldwide, with the implementation of the findings alleviating issues globally. As a supplement and alternative to gray infrastructure, GI has multiple integrated benefits. Multi-objective GI optimization seeks to provide maximum integrated benefits. The purpose of this review is to highlight the integrated multifunctional effectiveness of GI and to summarize its multi-objective optimization methodology. Here, the multifunctional effectiveness of GI in hydrology, energy, climate, environment, ecology, and humanities as well as their interrelationships are summarized. Then, the main components of GI multi-objective optimization including the spatial scale application, optimization objectives, decision variables, optimization methods and optimization procedure as well as their relationships and mathematical representation are examined. However, certain challenges still exist. There is no consensus on how to measure and optimize the integrated multi-functional effectiveness of GI. Future research directions such as enhancing integrated multi-objective assessment and optimization, improving life cycle analysis and life cycle cost, integrating benefits of GI based on future uncertainties and developing integrated green–gray infrastructure are discussed. This is vital for improving its integrated multifunctional effectiveness and the final decision-making of stakeholders.

Keywords: green infrastructure; multifunctional effectiveness; direct benefit; co-benefit; multi-objective optimization; life cycle analysis

1. Introduction

Sustainable urban development is faced with many challenges owing to climate change and urbanization [1]. Climate change is mainly characterized by average temperature rise and extreme precipitation trends [2,3], whereas urbanization is marked by intensive land development and related human activities [4]. The urban water cycle, for instance, has been significantly and directly affected by climate change and urbanization, leading to many urban water issues such as floods, water pollution, and ecological damage [5].

The basic natural hydrological cycle involves rainfall, evaporation, infiltration, runoff yield, and surface confluence [6]. Urban development leads to the creation of landfills in depressions, expansion of impermeable underlying surfaces, and changes to natural drainage paths [4]. Together with the increase in extreme precipitation events, these phenomena produce the "rain island effect" [7]. The natural water cycle, especially the runoff yield and surface confluence, has undergone profound changes under such development, with the total runoff and peak flow having significantly increased. The single objective of traditional gray infrastructure is to drain rainwater from the urban built environment, which is an inelastic approach that is incapable of coping with intensifying climate change and increasing urbanization [8]. Moreover, urban rainwater runoff transports large amounts of pollutants directly into water bodies [9]. In cities with combined sewer systems, untreated sewage is discharged into nearby water bodies during rainfall; this is known as combined sewer overflow (CSO) [10]. In addition, the continuous expansion of urbanization weakens the overall connectivity of ecological patches and corridors in an area [11].

Green infrastructure (GI) is a natural solution. The definition of GI is manifold, and different fields have different emphasis. The UN defines GI as a strategically planned network of natural and semi-natural areas to deliver a wide range of ecosystem services [12]. The US EPA defines GI as a method of water management that focuses on creating ecosystems to treat polluted stormwater runoff prior to it entering waterways [13]. Although no global definition has been agreed upon, the concept has a number of key features. The green infrastructure (GI) discussed in this review is a decentralized stormwater management practice network substituting or supplementing the gray infrastructure. GI focuses on stormwater management at the source, mimicking the natural hydrological cycle and flattening the stormwater runoff curve, thus optimizing the hydrological activities in urban areas [14]. Therefore, it provides many environmental, ecological, economic, and social benefits or services. Moreover, because of the low cost and ease of transformation and upgrading, its popularity is accelerating recently [15]. Globally, many countries have adopted measures to actively promote GI application. For example, implementing the Sponge City Strategy paved the way for GI development in China [16]. Other concepts and practices such as low impact development (LID) and best management practice (BMP) [17], are collectively referred as GI in this review for simplicity.

GI's versatility and the tools for assessing and optimizing the multiple benefits have received considerable attention. Hansen and Pauleit [18] summarized GI multifunctionality, proposing an evaluation framework related to ecosystem services. Additionally, Jayasooriya and Ng [19] proposed tools for modeling stormwater management and the economics of GI practices. Further, Kuller et al. [20] reviewed tools for planning GI practices and presented a novel planning suitability framework. In addition, Eckart et al. [21] reviewed methods for optimizing, modelling, and monitoring the performance of the GI alternatives. Subsequently, Li et al. [14] examined the operating mechanisms and effectiveness of GI widely used for stormwater management. Additionally, Zhang and Chui [22] reviewed strategies and tools for optimizing the spatial allocation of GI based on decision variables.

The goal of the GI optimization approach is to develop a decision-support tool for optimally selecting and placing GI practices to achieve an optimal overall benefit. The geographic information system (GIS), hydrological models, and optimization algorithms are frequently utilized for coupling and integration to comprehensively analyze the overall benefits of GI [23]. However, the choice of decision objectives varies greatly among different projects, and a unified standard on the integration or comparison of the multiple benefits under any sector are still lacking, which brings uncertainty in the expansion of GI practice. In addition, several benefits of GI are not taken into account in the evaluation process, which will also influence the rationality of decision-making. Nevertheless, any cost-benefit analysis comparing gray infrastructure and GI remains incomplete if the multiple possible benefits of GI are not considered [24]. Therefore, the measurement and optimization of the integrated benefits of GI are important areas that require further research. To further prompt the research and application of GI and provide stronger technical support to stakeholders and decision makers, the current research results of these evaluations need to be summarized and future research directions need to be discussed. This review commences with the multiple benefits of GI and the optimization methods based on the optimization objective of maximizing the overall benefit. The aims of this study are (1) to refine the benefits of GI and provide quantitative methods for assessing different benefits, and highlight the importance of the integrated benefits in decision-making; (2) to evaluate the multi-objective methodology for GI optimization including the optimization procedure, optimization objectives, decision variables, and optimization methods; and (3) to identify potential research areas within the GI multi-objective-based optimization methods.

2. Methodology

The main steps of this study are shown in Figure 1. In this review, approximately 100 review papers and research articles were consulted and their content exploited. We identified relevant literature by searching the Web of Science database using combinations of keywords like benefit, cost-benefit analysis, function, effectiveness, assessment, green infrastructure, optimization, low impact development, best management practice, optimum, and multi-criteria. Then, through screening and classification, all the literature contents were classified into two subjects, namely integrated multi-functional effectiveness of GI and multi-objective optimization methodology of GI. The relationship between the two subjects is that the former is the theoretical basis of the latter and the latter is the practical approach of the former. The progress and findings of the two subjects were reviewed respectively. Based on the literature review, the current shortcomings and challenges were identified. Finally, future research directions were proposed. This review is valuable for decision-makers and stakeholders to assess the comprehensive benefits of GI and to better understanding these benefits, which are important for promoting its implementation.

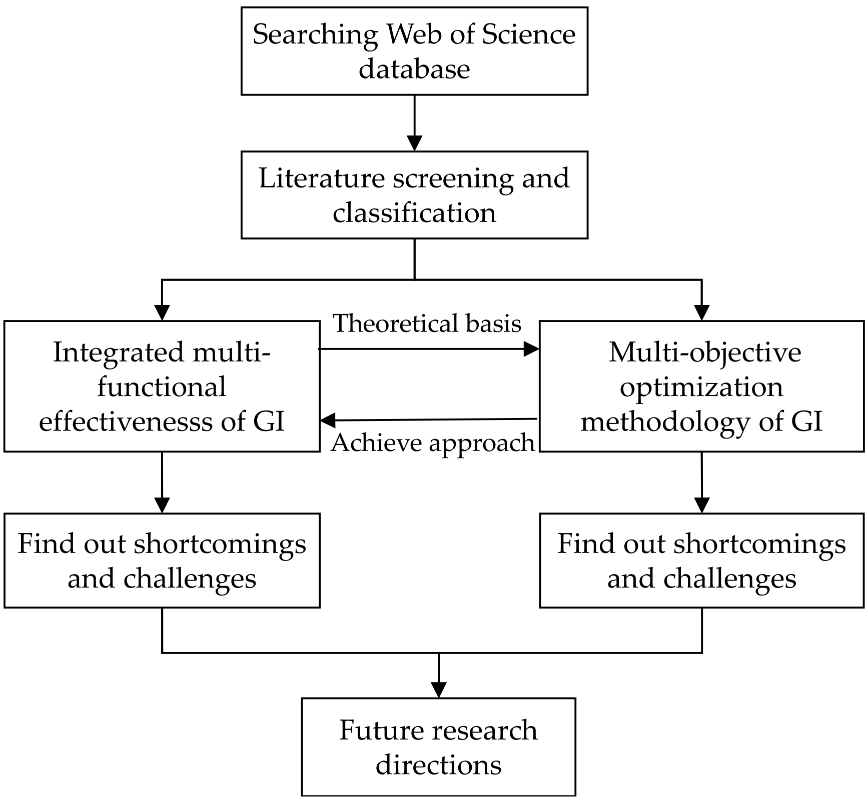

Figure 1. Main steps of this study.

3. Multi-Functional Effectiveness of GI

3.1. Functions and Benefits

GI effectiveness is reflected by its function and benefit. The functions of GI include infiltration, retention, storage and utilization of rainwater, purification, insulation of the vegetation and soil layer, regulating evapotranspiration and heat absorption, carbon sequestration by vegetation and the provision and improvement of habitat and green space (Figure 2). Through its functions, GI provides direct benefits and co-benefits. These benefits are often classified based on the ecosystem services framework comprising four major categories including provisioning, regulating, supporting, and cultural services [25,26]. To augment the interdisciplinary perspective, a new classification partitioning the benefits into hydrology, energy, climate, environment, ecology, and humanities was adopted. The functions and benefits of GI as well as their interdependence are displayed in Figure 2.

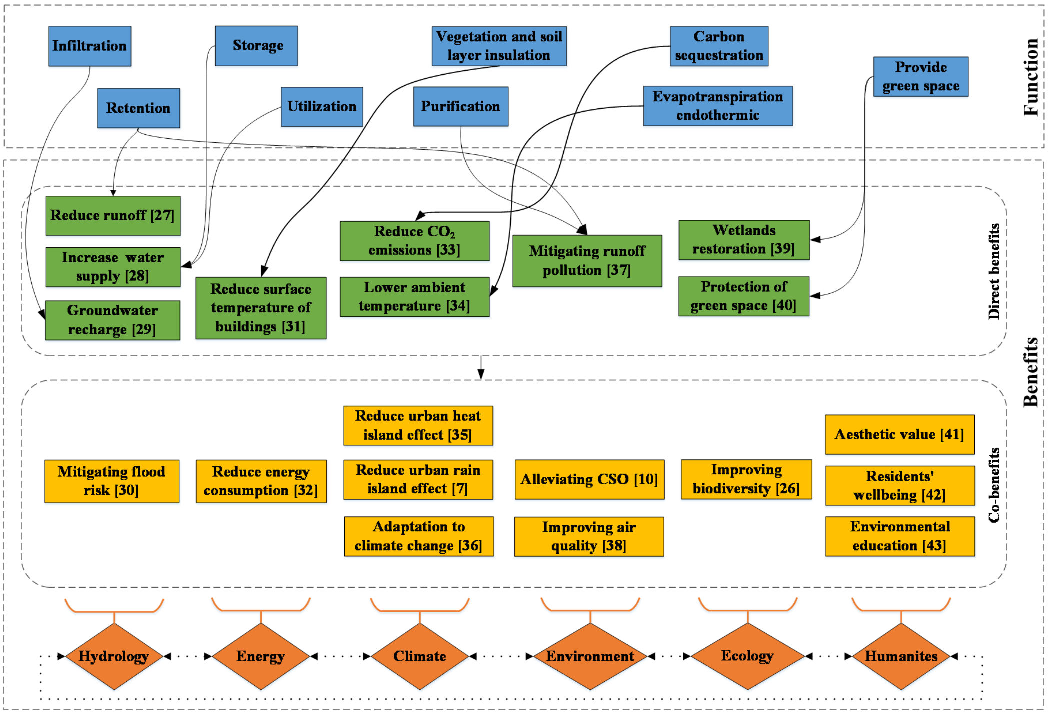

Figure 2. The effectiveness of green infrastructure (GI) and the relationships between the functions and benefits. (Direct benefits and co-benefits are distinguished as follows: the direct benefits of GI are generated by the output or service provided, whereas the co-benefits involve the contribution to other fields caused by the direct benefit.) [7,10,26–43].

3.2. *Assessment of the Effectiveness*

GI is sustainable and its multifunctional benefits often have a cumulative effect. Life cycle analysis (LCA) has been widely used in assessing the benefits of GI [44]. LCA is a systematic and relative tool for helping decision makers compare all environmental impacts throughout a life cycle when choosing between alternative courses of action [45]. Compared with the single-objective grey infrastructure, the benefits of GI increase over time [46]. The multi-functional effectiveness of GI discussed below all applies to the LCA framework.

The benefits of GI in hydrology, which represents the original intention of GI practice is fundamental. Field studies, the storm water management model (SWMM) model, and the rational method are employed for calculating or simulating hydrological performance [14]. Urban hydrological processes are optimized through the infiltration, retention, storage, and reuse of rainwater, thereby reducing runoff into urban drainage systems and water bodies. The evaluation indicators comprise the total runoff reduction, peak flow reduction, and peak lag time [47]. Changes in the runoff process after implementing GI are displayed in Figure 3.

Two-dimensional (2D) or one-dimensional (1D) and 2D coupled models are commonly utilized to assess the benefit of flooding mitigation by GI. The 2D hydrological model accurately predicts flooded areas, and is vital for identifying the best locations for GI applications. The evaluation indices comprise the inundation time, depth and scope [48]. A crucial element in the usability of flood inundation models is whether or not the model can display flood protection measures [49].

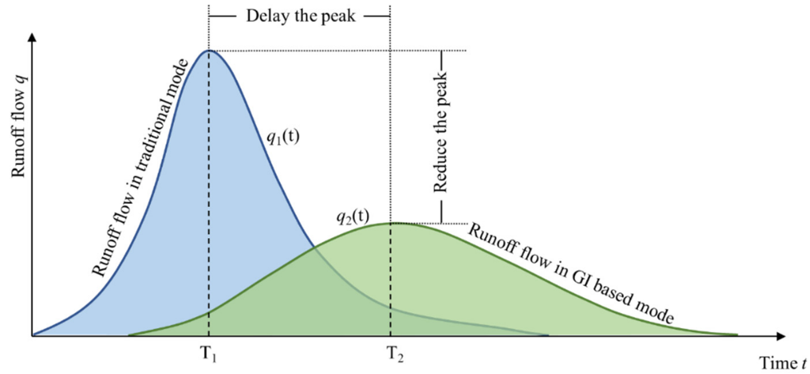

Figure 3. Comparison of the runoff process before and after GI implementation.

GI has considerable potential for energy saving and reducing the carbon footprint of traditional drainage systems. The carbon emission reduction pathway is illustrated in Figure 4. Function-based carbon emission reduction benefits of GI include hydrological, temperature, and water supply regulation as well as vegetation sequestration. For hydrological regulation, GI effectively reduces the total rainwater runoff, peak flow, and the use of rainwater pumping stations [50]. In a combined sewer system,the amount of runoff entering wastewater pumping stations and wastewater treatment plants is also effectively reduced [50]. An urban-scale study indicated that the rate of annual greenhouse gas emissions in the hydrological cycle decreased by 45.9% as an average in GI-based urban drainage system [32]. For temperature regulation, a green roof reduces the surface temperature of a building through the thermal insulation provided by the vegetation and soil layers while also improving evapotranspiration and heat absorption, thus reducing the need for an air conditioning system [31,51]. Moreover, rainwater recycling facilities reduce the demand for water in the water supply system by recycling rainwater for irrigation and road flushing, thereby minimizing the corresponding carbon emissions of the water supply system [52]. Vegetation in GI also exhibits carbon sequestration potential [33]. In addition, GI is commonly cheaper and consumes less energy than traditional gray infrastructure over the entire life cycle of material production, transportation, facility construction, and operation and maintenance [46].

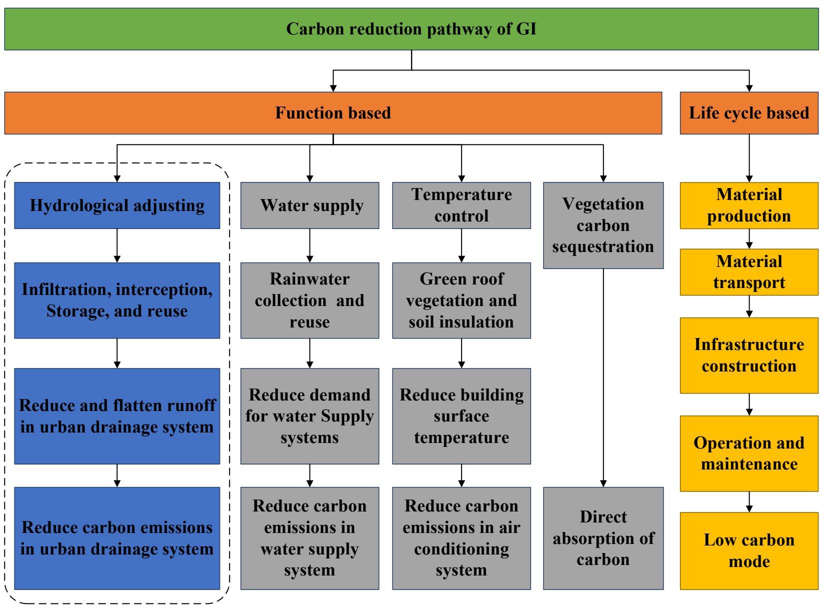

Figure 4. Carbon reduction pathway of GI based on the functionality and life cycle [31–33,46,50–52]. The figure represents a summary of the cited references.

Climate change causes extreme precipitation events [3], and the future climate prediction model of Hirabayashi et al. [2] suggests that the global flood risk will be proportional to the extent of climate warming. Therefore, GI can improve the resilience of cities to the impacts of climate change by mitigating the urban 'rain island effect' [7].

GI measures have demonstrated promise for mitigating air pollution in urban areas across the world [38]. A widely used technique for assessing the pollution reduction capability of GI is the dry deposition modeling. Jayasooriya et al. [38] employed the concept of dry deposition modeling to quantitatively analyze the benefit of GI to local air quality.

Urban rainwater runoff transports diverse components such as pathogens, nutrients, sediments, and heavy metals to water bodies [9]. GI implementation reduces such runoff, helping to reduce the risk of water pollution and CSO [10]. Total amounts or removal efficiencies of pollutants such as the total suspended solid (TSS), biochemical oxygen demand (BOD), chemical oxygen demand (COD), total phosphorus (TP), and total nitrogen (TN) are usually considered as evaluation indices for pollutant removal [53–55].

There is consensus that GI can aid in maintaining and restoring ecosystems, generate ecosystem services like habitat provision and wildlife dispersal, and improve biological diversity [56,57]. Connop et al. [26] used the invertebrates to represent the contribution of GI to biodiversity, while Radinja et al. [58] employed the GI size to demonstrate the environmental benefits of providing habitats.

GI can also improve local recreation by enhancing the aesthetic and cultural value of places, which are valuable for human health and happiness [42]. GI is also environmentally educational [43]. However, these benefits are frequently characterized as subjective, thereby making quantification difficult [59]. Questionnaires are usually the first choice of subjective measures [60]. To quantify them, some studies have tried to translate these subjective benefits into indices in landscape ecology or economics. Casado-Arzuaga et al. [61] established a GIS-based social–ecological approach to estimate the value of recreation and aesthetic services. Tomalty et al. [62] offered a guidance in attributing economic value to property values, marketing benefits, food production and food security, sound attenuation, stormwater retention, air quality, and greenhouse gas sequestration of green roofs.

3.3. Literature Analysis

Among the 42 studies on GI optimization exploited, hydrology-related indices such as the runoff quantity and quality dominate the functional indices, with subordinate influences for other indices including energy, ecology, climate, environment, and humanities, as displayed in Figure 5. The results demonstrate that most studies on GI optimization are hydrology-related, with a focus on flood control and mitigation benefits as well as the environmental benefits of runoff quality management. These results indicate that an integrated multifunctional approach involving energy, ecology, climate, and humanities for GI remains a major concern.

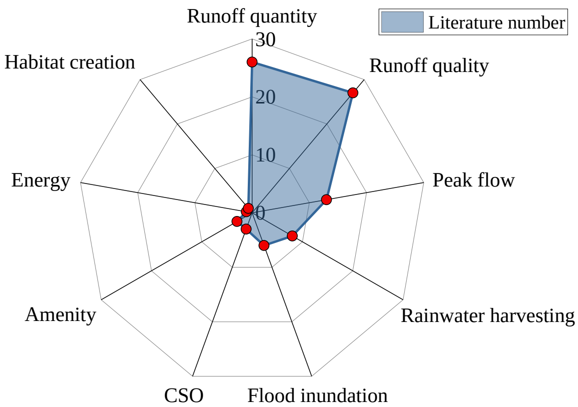

Figure 5. Plot showing functional indicators for GI and the number of studies involved.

4. Multi-Objective Optimization Methodology

4.1. Spatial Scale

The application scale of GI optimization includes the city region, watershed, catchment, block, and site. An inclusion relationship exists between the spatial scales, as shown in Figure 6. Clearly, applying GI intensely over a small scale is easier, characterized by an obvious hydrological impact. However, the effects of GI on the stream baseflow are diffuse at such small scales [63]. Certainly, a big-picture perspective may not be needed when focusing on a closed catchment system. The overall implementation of a water management strategy on the watershed and catchment scale involves cumulative effects [64,65]. Cibin and Chaubey [66] developed a multi-level spatial optimization (MLSOPT) approach for solving complex watershed scale optimization. MLSOPT works at two levels: a watershed is divided into small catchments and each catchment is optimized individually. Then the optimum catchment solutions are used for watershed scale optimization [66]. This method of classification can realize the parallel computation of different catchments, greatly improving computational efficiency, and can also determine the optimization objectives of each catchment according to the location and function of each catchment in the watershed.

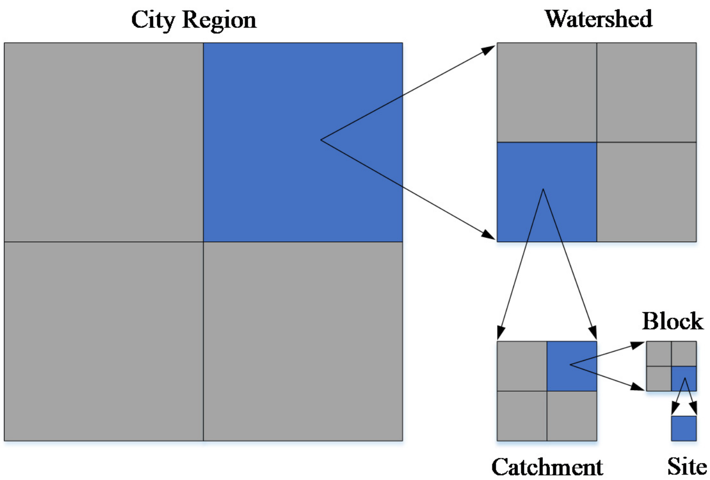

Figure 6. Illustration of inclusion relationships between different spatial scales.

4.2. Optimization Objectives

The optimization goal is to produce the maximum integrated multifunctional effectiveness. Therefore, multi-objective optimization is now a popular method involving tradeoff solutions at different special scales [67]. Evaluation criteria are used to build objective functions to support decision-making. Objective functions are usually developed based on the multifunctional effectiveness and the cost, and these are typically expressed by Equations (1) as:

$$\text{Max}\, Effectiveness_k = f_k(x_1, x_2, x_3, \cdots, x_n) \tag{1}$$

where $x_1, x_2, x_3, \ldots, x_n$ are the decision variables and k is the effectiveness number.

4.3. Decision Variables

The decision variables are exploited for selecting and placing the BMPs and LID practices, and these involve the type, size, and location [22]. In the optimization process, GI database is built by assigning values to type, size, and location. The optimization algorithm is then utilized for iterating the decision variables, thereby producing the optimal scheme. Internal relationships exist among the type, size, and location, and these potentially influence the overall effectiveness of GI. The specific contents of the three main decision variables for GI optimization are displayed in Figure 7.

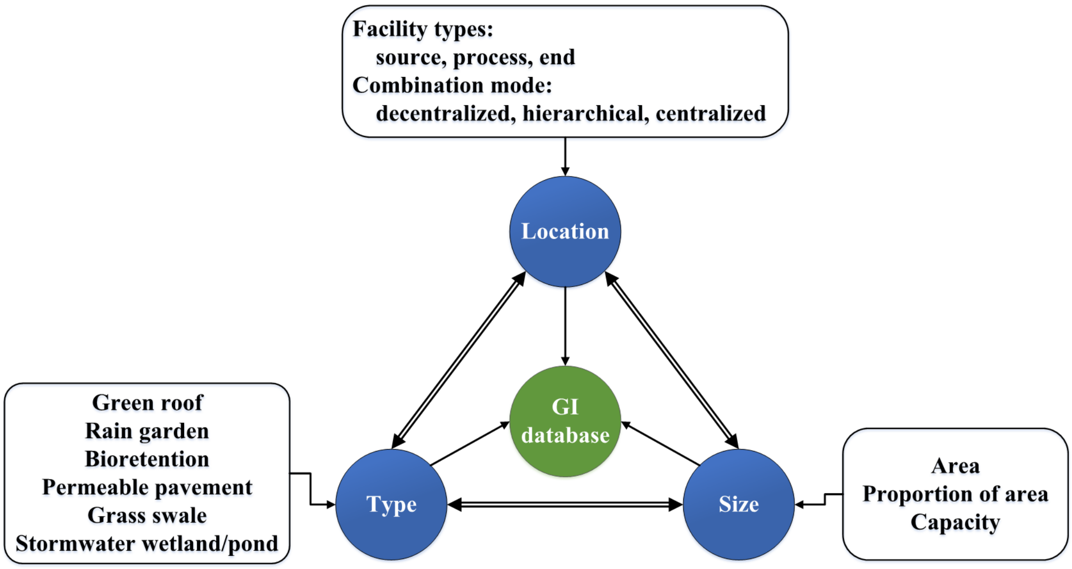

Figure 7. Illustration of the three main decision variables for GI optimization and their contents.

The facility types include green roofs, rainwater gardens, bioretention sites, permeable pavements, and rainwater wetlands/pond. Liu et al. [14] and Li et al. [68] summarized the performance strengths of individual GI measures. Indicators representing the sizes of different facility types also involve varied forms. Facility area, percentage of the facility area in the catchment area, and facility capacity are commonly employed to represent the size [69,70]. Figure 8 shows the locations of GI and the types of combined patterns using the watershed scale as an example. According to the water flow paths in the study area, GI facilities fall into three types including the source, process, and end [71]. The source facility is often small and decentralized, and it is mainly used to reduce stormwater runoff at the catchment area source. Meanwhile, the process facility transmits stormwater runoff overflow from the source facility, while the end facility is located downstream of the watershed, serving for high stormwater runoff retention and downstream pressure reduction [72]. The modes of GI combination can generally be classified into centralized, decentralized, and hierarchical modes [22,73]. Decentralized or hierarchical modes are advocated, and are closer to natural hydrological processes [22]. Conversely, for recreation and biodiversity, larger green patches or corridors are better because distributed GI is more vulnerable to urbanization.

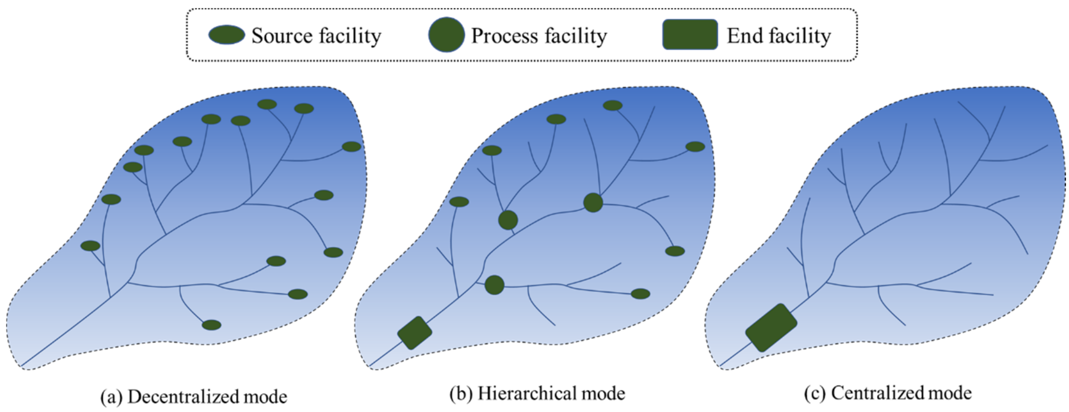

Figure 8. Locations and combined patterns of GI at the watershed scale.

4.4. Optimization Method

In the decision-making process, commonly, more than two stakeholders with different effectiveness preferences are involved, and this may be characterized by conflicts. However, bargaining methods and the game theory are usable for finding a stable solution for multi-criteria decision-making [74]. This solution combines the individual effectiveness preferences into a collective and interpreted choice for integrating stakeholder perspectives in the assessments [27]. When no consensus exists regarding the rank of criteria in most stakeholder domains, the equal weight for all criteria is proposed as a solution [58,67,75,76]. Expert scoring [77] and analytic hierarchy process [78] are also used to weigh different functional effectiveness.

Contrary to the scenario analysis, the optimization algorithm is capable of evaluating high numbers of potential solutions automatically, thereby enabling the exploration of tradeoffs between multiple objectives. Many optimization algorithms exist, including the genetic algorithm (GA), simulated annealing (SA), ant colony optimization (ACO), greedy, breadth first search (BFS), generalized pattern search (GPS), linear programming (LP), and artificial neural network (ANN), Technique for order of preference by similarity to ideal solution (TOPSIS) and shuffled frog leaping algorithm (SFLA). Among the optimization algorithms mentioned above, LP is a mathematical method and the others are artificial intelligence methods. Mathematical methods offer the advantages of less computation and fast convergence. The disadvantage of using mathematical methods is that they can only identify the local optimal solution, and the optimization results strongly depend on the initial value selected. While artificial intelligence methods can obtain the global optimal solution and the optimization results are not affected by the initial conditions, they require considerable computation, and convergence is slow. Evolutionary algorithms (EAs) are linked to biological evolution mechanisms (e.g., reproduction, mutation, crossover, and selection) and are among the most efficient metaheuristics for solving water management practice issues [79]. Selection of optimization algorithms is vital in spatial optimization to ensure convergence of objective functions. NSGA-II is widely applied in GI optimization studies because it involves an elitist approach, provides a neat spread of solutions, and supports the finding of the entire Pareto front [80]. A multi-algorithm genetically adaptive multi-objective (AMALGAM) [67] and optimization software toolkit for research involving computational heuristics (OSTRICH) [81] are multi-algorithm methods that combine the strengths of multiple optimization algorithms, many of which are parallelized. Some models have achieved the built-in of optimization algorithms, hydrological simulations, and cost-benefit analysis, such as SUSTAIN [82].

4.5. Optimization Procedure

An optimization model is explicitly aimed at identifying the blend of design variables that produce the best result for a stated objective or objectives, subject to meeting all constraints on the system [19]. The constraints usually involve the cost, available land, planning, and other legal restrictions. Figure 9 illustrates how the optimization approach is realized to achieve the optimal hydrological benefits by taking the SWMM model coupled with NSGA-II as an example [30]:

1. Determination of the scale at which the optimization program will operate.
2. Identifying objectives of the optimization program, selecting decision variables, and constraints of the optimization scheme.
3. Choose original decision variables of GI.
4. Using the SWMM models to assess the hydrological effectiveness of GI scheme.
5. Run NSGA-II. The SWMM model and the optimization algorithm are intercycled to realize automatic searching of the optimal design parameters.
6. Optimization complete and generate the Pareto front that corresponds to a set of optimal solutions, so-called nondominated solutions.

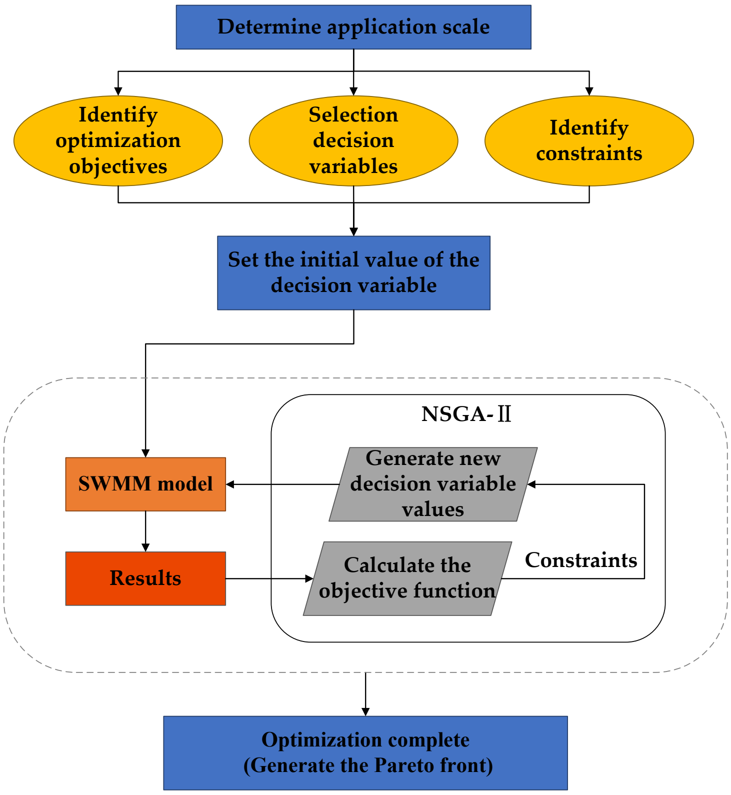

Figure 9. Schematic of the GI optimization procedure.

4.6. Literature Analysis

Based on the multi-objective optimization methods for GI analyzed, the spatial scale, multi-objectives, decision variables, and optimization methods in 42 studies were exploited, as shown in Figure 10 and presented in Table 1. According to Figure 10, studies at the watershed and catchment scales account for the majority, with two and three dominating the number of objectives. Overall, 54.8% of the studies considered three decision variables including the type, size, and location. The optimization algorithms selected are generally diverse, although the NSGA II predominates.

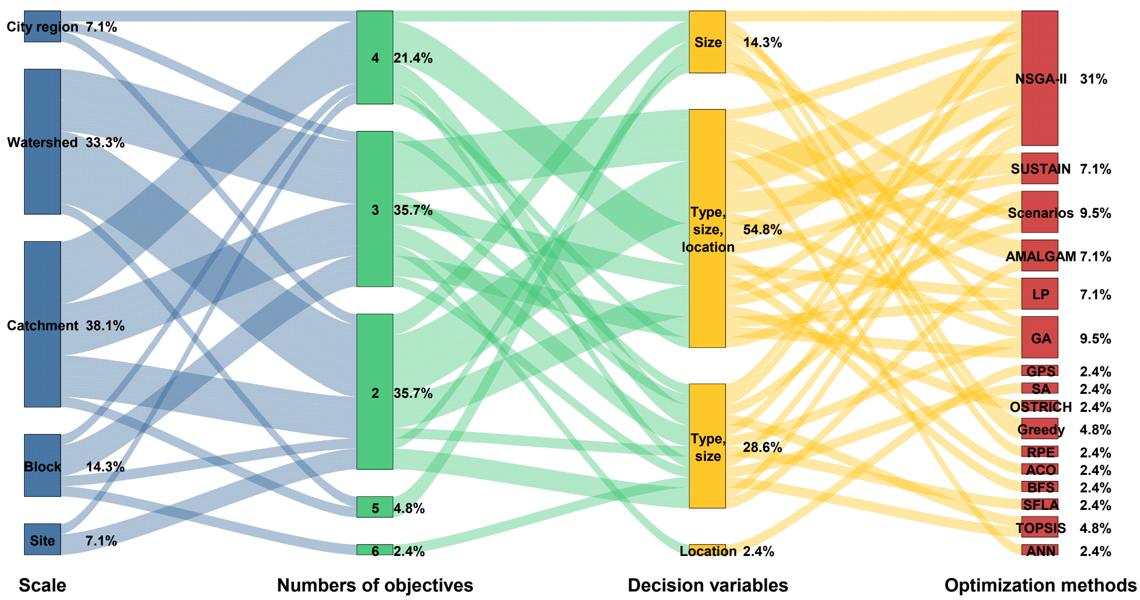

Figure 10. Alluvial diagram for different studies examined in this study.

Table 1. Summary of data for optimization studies used for evaluating the GI practices.

Source	Scale	Objectives	Decision Variables	Optimization Methods
	○City Region ●Watershed ◎Catchment ♦Block □Site	■Cost □Runoff Volume ▲Runoff Quality △Peak Flow ▼Rainwater Harvesting ▽Flood Inundation ●CSO ◎Amenity ♦Energy ◇Habitat Creation	● Type ◎ Size ○ Location	
Baek et al. [83]	□	♦ □ ▲ △	● ◎ ○	Scenarios
Montaseri et al. [84]	♦	♦ □ ▲	● ◎ ○	GA
Yang and Best [80]	●	♦ ▲	● ◎ ○	NSGA-II
Chen et al. [37]	●	♦ ▲	● ◎ ○	NSGA-II
Ghodsi et al. [27]	●	♦ □ ▲	● ◎ ○	NSGA-II
Jayasooriya et al. [85]	♦	♦ ▲	◎	Scenarios
Liu et al. [67]	□	□ ▲	● ◎	AMALGAM
Liu et al. [86]	●	♦ □ ▲	● ◎ ○	AMALGAM
Mao et al. [82]	◎	♦ □ ▲ △	● ◎ ○	SUSTAIN
Marchi et al. [28]	□	♦ ▼	● ◎	NSGA-II
Sebti et al. [87]	●	♦ □ △	● ◎ ○	LP
Sun et al. [69]	●	♦ △	● ◎ ○	SUSTAIN
Aminjavaheri and Nazif [76]	◎	♦ □ ▽	● ◎	NSGA-II
Cano and Barkdoll [75]	◎	♦ □	● ◎ ○	Scenarios
Di Matteo et al. [88]	◎	♦ □ ▲ ▼	● ◎ ○	NSGA-II
Fan et al. [89]	●	♦ □	● ◎ ○	SUSTAIN
Giacomoni and Joseph [90]	◎	♦ □ ▲ ▽	● ◎ ○	NSGA-II
Liu et al. [91]	●	♦ □ ▲	● ◎ ○	AMALGAM
Li et al. [92]	○	♦ □ ▲ ▼	◎	NSGA-II
Wang et al. [93]	◎	♦ ▲ ▽	○	GPS
Xu et al. [94]	♦	♦ □ ▲ △	● ◎	NSGA-II
Dai et al. [95]	●	♦ ▲	● ◎ ○	GA
Azari and Tabesh [77]	◎	♦ ▽	● ◎ ○	NSGA-II
Eckart et al. [96]	◎	♦ ▲ △	● ◎	GA
Huang et al. [30]	♦	♦ △ ▽	● ◎	SA
Jayasooriya et al. [97]	♦	♦ □ ▲ △ ▼ ◎	● ◎	TOPSIS
Li et al. [98]	○	♦ ▼ ♦	● ◎	NSGA-II
Macro et al. [81]	◎	♦ ●	● ◎ ○	OSTRICH
Xu et al. [99]	●	♦ □ ▲ △ ▼	◎	Greedy
Yang and Chui [100]	◎	□ △ ▽ ♦ ●	◎	RPE
Alamdari and Sample [101]	●	♦ □ ▲	● ◎	NSGA-II
Di Matteo et al. [53]	◎	♦ ▲ ▼ ◎	● ◎ ○	ACO
Helmi et al. [102]	◎	♦ □ △	● ◎ ○	BFS
Liu et al. [103]	◎	♦ ▲	● ◎	SFLA
Luan et al. [104]	◎	♦ □ ▲ △	● ◎	TOPSIS
Radinja et al. [58]	◎	♦ ● ◎ ◇	● ◎	Scenarios
Torres et al. [105]	♦	♦ □ ▼	● ◎ ○	LP
Wang et al. [106]	◎	♦ □ ▲	● ◎ ○	LP
Xu et al. [70]	○	♦ ▲	◎	Greedy
Ghodsi et al. [107]	●	♦ □	◎	GA
Geng et al. [108]	●	♦ ▲	● ◎ ○	NSGA-II
Latifi et al. [74]	●	♦ □ ▲	● ◎ ○	ANN

5. Future Research Directions

5.1. Enhancing Integrated Multi-Objective-Based Assessment and Optimization

In this review, a multi-functional conceptual framework for GI involving hydrology, energy, climate, environment, ecology, and humanities is proposed. Multidisciplinary approaches and interdisciplinary collaboration are critical but challenging, especially for compact cities [109]. GI installation often requires space, and this involves a trade-off between land use, in order to achieve the optimal integrated benefits in the larger perspective of urban planning. In addition, Wolch et al. [110] reported that paradoxes are evident in urban green strategies; for example, the creation of green space can make a neighborhood healthier and more aesthetically valuable, but it can also increase housing costs and property values. Therefore, how to integrate the comprehensive benefits of green infrastructure in different fields needs more discussion.

5.2. Improving Life Cycle Analysis (LCA) and Life Cycle Cost (LCC)

Cost-benefit analysis is employed as the main method for investment decision-making, to minimize the investment while maximizing the benefit. Compared with the gray infrastructure's singular goal, GI, as a municipal or private investment, usually exhibits better cost-benefit outcomes over the entire life cycle, providing numerous benefits in addition to rainwater management [23]. Life cycle cost (LCC) is based on LCA but considers cost rather than environmental impacts. LCC is therefore defined as the process of determining the sum of all expenses associated with the complete life cycle of a product system, including material acquisition, installation, operation, maintenance, and disposal costs [44].

Of the 42 studies reviewed, 21 involved an LCA for GI benefits, with lifespans ranging from 10 to 50 years. Of the 41 studies involving the economic costs of GI, only 6 considered LCC. Zuo et al. [111] noted that combining the LCA and LCC is essential for decision-making when assessing the sustainable benefits of individual projects.

5.3. Integrating Benefits of GI Based on Future Uncertainties

Stormwater management will face major challenges in future because of climate change and urbanization. Therefore, recognizing the risks and adaptively planning through the GI practice is important [112]. The optimal integrated benefits scheme under current conditions may not be optimal in the future. However, most optimization frameworks do not address the future uncertainty and GI practice robustness related to possible future conditions. Importantly, the static planning strategies must be changed to dynamic adaptation strategies with time, based on future uncertainties [113]. Such future conditions are quantifiable by developing scenarios associated with the temporal and spatial changes in climate and the socio-economic environment [114]. Xu et al. [70] used the annual rainfall variation attributed to climate change to generate future climate data. Liu et al. [91] utilized the land use type changes to represent the future extent of urbanization. Given the uncertainty of future climate and environmental change, how to achieve optimal integrated benefits under future conditions requires continuous attention.

5.4. Developing Integrated Green–Gray Infrastructure

A consensus is emerging that reliability, resilience, and sustainability must be considered in the planning or upgrading of urban stormwater infrastructure [115,116]. This implies that there is a need to support the development of strategies for the reliable provision of services while explicitly addressing the need for greater resilience to emerging threats, and providing sustainable solutions. The design criteria of GI are mainly applicable to small and medium rainfall events. The flood risk mitigation capacity of GI is limited under excessive rainfall conditions [53]. Although GI can provide comprehensive benefits, these structures cannot fully replace gray infrastructure, especially in developing countries with inadequate infrastructure [117]. Considering these limitations, integrated green–gray infrastructure is considered to be a tradeoff solution to ensure robustness in extreme events and to provide common benefits to the environment and society [118]. Butler et al. [116] and Casal-Campos et al. [119], based on a reliable, resilient, and sustainable framework, compared green, gray, and combined green–gray drainage strategies. They reported that the combined green–gray strategy offered better comprehensive benefits and provided an enhanced robustness potential. This demonstrates that simply optimizing GI remains insufficient for achieving optimal comprehensive benefits. In the future, gray and green facilities should be combined to perform comprehensive optimization of urban rainwater infrastructure.

6. Conclusions

In recent years, the comprehensive benefits of GI have received increasing attention. This review analyzed studies related to the integrated multi-functional effectiveness of GI and multi-objective optimization methodology of GI. The following conclusions can be drawn:

(1) A multi-functional conceptual framework for GI involving hydrology, energy, climate, environment, ecology, and humanities is proposed. This framework expresses the functions of GI, as well as the direct benefits and co-benefits through GI functions. Although we already have a better understanding of the multi-functional effectiveness of GI, there is no consensus on how to measure the integrated multi-functional effectiveness of GI.

(2) A number of research papers on the multi-objective optimization of GI have been summarized. The primary objective is to maximize the integrated benefits for decision-making on GI. The optimization method is usually coupled with an effectiveness evaluation model and an optimization algorithm under a specific spatial scale and optimization goal. The pareto front is employed to find the optimal variables for GI decision-making including type, size, and location.

This review provides a resource for decision-makers in selecting appropriate methods for evaluating the effectiveness of GI and will help stakeholders better understand the benefits of GI, which are vital for promoting its implementation.

Future research should focus on the following: (1) improving the integrated multifunctionality of GI by strengthening multidisciplinary research and interdisciplinary cooperation; (2) enhancing the integration of life cycle analysis and life cycle cost; (3) paying attention to integrated benefits of GI based on future uncertainties; and (4) strengthening optimization research and the utilization of integrated green–gray infrastructure.

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References

1. Pumo, D.; Arnone, E.; Francipane, A.; Caracciolo, D.; Noto, L. Potential implications of climate change and urbanization on watershed hydrology. *J. Hydrol.* **2017**, *554*, 80–99. [CrossRef]
2. Hirabayashi, Y.; Mahendran, R.; Koirala, S.; Konoshima, L.; Yamazaki, D.; Watanabe, S.; Kim, H.; Kanae, S. Global flood risk under climate change. *Nat. Clim. Chang.* **2013**, *3*, 816–821. [CrossRef]
3. Donat, M.G.; Lowry, A.L.; Alexander, L.V.; O'Gorman, P.A.; Maher, N. More extreme precipitation in the world's dry and wet regions. *Nat. Clim. Chang.* **2016**, *6*, 508–513. [CrossRef]
4. Oudin, L.; Salavati, B.; Furusho-Percot, C.; Saadi, M. Hydrological impacts of urbanization at the catchment scale. *J. Hydrol.* **2018**, *559*, 774–786. [CrossRef]
5. Liu, J.H.; Wang, H.; Gao, X.R.; Chen, S.; Wang, J.; Shao, W. Review on Urban Hydrology (in Chinese). *Chin. Sci. Bull.* **2014**, *59*, 3581–3590.

6. Wang, H.; Jia, Y.W. Theory and study methodology of dualistic water cycle in river basins under changing conditions (in Chinese). *J. Hydraul. Eng.* **2016**, *47*, 1219–1226.
7. Yang, P.; Ren, G.; Yan, P. Evidence for a strong association of short-duration intense rainfall with urbanization in the Beijing urban area. *J. Clim.* **2017**, *30*, 5851–5870. [CrossRef]
8. Dong, X.; Guo, H.; Zeng, S. Enhancing future resilience in urban drainage system: Green versus gray infrastructure. *Water Res.* **2017**, *124*, 280–289. [CrossRef]
9. Aryal, R.; Vigneswaran, S.; Kandasamy, J.; Naidu, R.; Vigneswaran, S. Urban stormwater quality and treatment. *Korean J. Chem. Eng.* **2010**, *27*, 1343–1359. [CrossRef]
10. Montalto, F.; Behr, C.; Alfredo, K.; Wolf, M.; Arye, M.; Walsh, M. Rapid assessment of the cost-effectiveness of low impact development for CSO control. *Landsc. Urban Plan.* **2007**, *82*, 117–131. [CrossRef]
11. Yu, D.; Xun, B.; Shi, P.; Shao, H.; Liu, Y. Ecological restoration planning based on connectivity in an urban area. *Ecol. Eng.* **2012**, *46*, 24–33. [CrossRef]
12. European Commission (EC). *Green Infrastructure (GI)-Enhancing Europe's Natural Capital*; European Commission: Brussels, Belgium, 2013.
13. US Environmental Protection Agency (USEPA). What is Green Infrastructure? Available online: https://www.epa.gov/green-infrastructure/what-green-infrastructure (accessed on 5 September 2020).
14. Li, C.; Peng, C.; Chiang, P.; Cai, Y.; Wang, X.; Yang, Z. Mechanisms and Applications of Green Infrastructure Practices for Stormwater Control: A Review. *J. Hydrol.* **2019**, *568*, 626–637. [CrossRef]
15. Spatari, S.; Yu, Z.; Montalto, F.A. Life cycle implications of urban green infrastructure. *Environ. Pollut.* **2011**, *159*, 2174–2179. [CrossRef] [PubMed]
16. Wang, H.; Mei, C.; Liu, J.; Shao, W. A new strategy for integrated urban water management in China: Sponge city. *Sci. China Technol. Sci.* **2018**, *61*, 317–329. [CrossRef]
17. Fletcher, T.D.; Shuster, W.; Hunt, W.F.; Ashley, R.; Butler, D.; Arthur, S.; Trowsdale, S.; Barraud, S.; Semadeni-Davies, A.; Bertrand-Krajewski, J.-L.; et al. SUDS, LID, BMPs, WSUD and more—The evolution and application of terminology surrounding urban drainage. *Urban Water J.* **2014**, *12*, 525–542. [CrossRef]
18. Hansen, R.; Pauleit, S. From Multifunctionality to Multiple Ecosystem Services? A Conceptual Framework for Multifunctionality in Green Infrastructure Planning for Urban Areas. *AMBIO* **2014**, *43*, 516–529. [CrossRef]
19. Jayasooriya, V.M.; Ng, A.W.M. Tools for modeling of stormwater management and economics of green infrastructure practices: A review. *Water Air Soil Pollut.* **2014**, *225*, 2055. [CrossRef]
20. Kuller, M.; Bach, P.M.; Ramirez-Lovering, D.; Deletic, A. Framing water sensitive urban design as part of the urban form: A critical review of tools for best planning practice. *Environ. Model. Softw.* **2017**, *96*, 265–282. [CrossRef]
21. Eckart, K.; Mcphee, Z.; Bolisetti, T. Performance and implementation of low impact development—A review. *Sci. Total Environ.* **2017**, *607–608*, 413–432. [CrossRef]
22. Zhang, K.; Chui, T.F.M. A comprehensive review of spatial allocation of LID-BMP-GI practices: Strategies and optimization tools. *Sci. Total Environ.* **2018**, *621*, 915–929. [CrossRef]
23. Vandermeulen, V.; Verspecht, A.; Vermeire, B.; Van Huylenbroeck, G.; Gellynck, X. The use of economic valuation to create public support for green infrastructure investments in urban areas. *Landsc. Urban Plan.* **2011**, *103*, 198–206. [CrossRef]
24. Dandy, G.C.; Di Matteo, M.; Maier, H.R. Chapter 15—Optimization of WSUD Systems: Selection, Sizing, and Layout. In *Approaches to Water Sensitive Urban Design*; Sharma, A.K., Gardner, T., Begbie, D., Eds.; Elsevier: Amsterdam, The Netherlands, 2019; pp. 303–328.
25. Andersson, E.; Barthel, S.; Borgström, S.; Colding, J.; Elmqvist, T.; Folke, C. Reconnecting Cities to the Biosphere: Stewardship of Green Infrastructure and Urban Ecosystem Services. *AMBIO* **2014**, *43*, 445–453. [CrossRef] [PubMed]
26. Connop, S.; Vandergert, P.; Eisenberg, B.; Collier, M.J.; Nash, C.; Clough, J.; Newport, D.J. Renaturing cities using a regionally-focused biodiversity-led multifunctional benefits approach to urban green infrastructure. *Environ. Sci. Policy* **2016**, *62*, 99–111. [CrossRef]
27. Ghodsi, S.H.; Kerachian, R.; Zahmatkesh, Z. A multi-stakeholder framework for urban runoff quality management: Application of social choice and bargaining techniques. *Sci. Total Environ.* **2016**, *550*, 574–585. [CrossRef] [PubMed]

28. Marchi, A.; Dandy, G.C.; Maier, H.R. Integrated Approach for Optimizing the Design of Aquifer Storage and Recovery Stormwater Harvesting Schemes Accounting for Externalities and Climate Change. *J. Water Resour. Plan. Manag.* **2016**, *142*, 4016002. [CrossRef]
29. Bhaskar, A.S.; Hogan, D.M.; Nimmo, J.R.; Perkins, K.S. Groundwater recharge amidst focused stormwater infiltration. *Hydrol. Process.* **2018**, *32*, 2058–2068. [CrossRef]
30. Huang, C.; Hsu, N.; Liu, H.; Huang, Y.-H. Optimization of low impact development layout designs for megacity flood mitigation. *J. Hydrol.* **2018**, *564*, 542–558. [CrossRef]
31. Kaiser, D.; Kohler, M.; Schmidt, M.; Wolff, F. Increasing Evapotranspiration on Extensive Green Roofs by Changing Substrate Depths, Construction, and Additional Irrigation. *Buildings* **2019**, *9*, 173. [CrossRef]
32. Liu, J.; Wang, J.; Ding, X. Assessing the mitigation of greenhouse gas emissions from a green infrastructure-based urban drainage system. *Appl. Energy* **2020**, *278*, 115686. [CrossRef]
33. Moore, T.L.C.; Hunt, W.F. Predicting the carbon footprint of urban stormwater infrastructure. *Ecol. Eng.* **2013**, *58*, 44–51. [CrossRef]
34. Christopher, A.; Jason, B.; Tony, M. Cultivating climate justice: Green infrastructure and suburban disadvantage in Australia. *Appl. Geogr.* **2017**, *89*, 52–60.
35. Mohajerani, A.; Bakaric, J.; Jeffrey-Bailey, T. The urban heat island effect, its causes, and mitigation, with reference to the thermal properties of asphalt concrete. *J. Environ. Manag.* **2017**, *197*, 522–538. [CrossRef] [PubMed]
36. Matthews, T.; Lo, A.Y.; Byrne, J.A. Reconceptualizing green infrastructure for climate change adaptation: Barriers to adoption and drivers for uptake by spatial planners. *Landsc. Urban Plan.* **2015**, *138*, 155–163. [CrossRef]
37. Chen, L.; Wei, G.; Shen, Z. Incorporating water quality responses into the framework of best management practices optimization. *J. Hydrol.* **2016**, *541*, 1363–1374. [CrossRef]
38. Jayasooriya, V.M.; Ng, A.W.M. Green infrastructure practices for improvement of urban air quality. *Urban For. Urban Green.* **2017**, *21*, 34–47. [CrossRef]
39. Ruckelshaus, M.H.; Guannel, G.; Arkema, K.; Verutes, G.; Griffin, R.; Guerry, A.; Silver, J.; Faries, J.; Brenner, J.; Rosenthal, A. Evaluating the Benefits of Green Infrastructure for Coastal Areas: Location, Location, Location. *Coast. Manag.* **2016**, *44*, 504–516. [CrossRef]
40. Karen, H. Green infrastructure: Reconciling urban green space and regional economic development: Lessons learnt from experience in England's north-west region. *Local Environ.* **2011**, *16*, 963–975.
41. Ives, C.D.; Oke, C.; Hehir, A.; Gordon, A.; Wang, Y.; Bekessy, S.A. Capturing residents' values for urban green space: Mapping, analysis and guidance for practice. *Landsc. Urban Plan.* **2017**, *161*, 32–43. [CrossRef]
42. Kim, G.; Miller, P.A. The impact of green infrastructure on human health and well-being: The example of the Huckleberry Trail and the Heritage Community Park and Natural Area in Blacksburg, Virginia. *Sustain. Cities Soc.* **2019**, *48*, 101562. [CrossRef]
43. Giusti, M.; Svane, U.; Raymond, C.M.; Beery, T.H. A Framework to Assess Where and How Children Connect to Nature. *Front. Psychol.* **2017**, *8*, 2283. [CrossRef]
44. Xu, C.; Jia, M.; Xu, M.; Long, Y.; Jia, H. Progress on environmental and economic evaluation of low-impact development type of best management practices through a life cycle perspective. *J. Clean. Prod.* **2019**, *213*, 1103–1114. [CrossRef]
45. Wang, Y.; Ni, Z.; Hu, M.; Li, J.; Wang, Y.; Lu, Z.; Chen, S.; Xia, B. Environmental performances and energy efficiencies of various urban green infrastructures: A life-cycle assessment. *J. Clean. Prod.* **2020**, *248*, 119244. [CrossRef]
46. De Sousa, M.R.C.; Montalto, F.A.; Spatari, S. Using Life Cycle Assessment to Evaluate Green and Grey Combined Sewer Overflow Control Strategies. *J. Ind. Ecol.* **2012**, *16*, 901–913. [CrossRef]
47. Liu, W.; Chen, W.; Peng, C. Assessing the effectiveness of green infrastructures on urban flooding reduction: A community scale study. *Ecol. Model.* **2014**, *291*, 6–14. [CrossRef]
48. Schubert, J.E.; Burns, M.D.; Fletcher, T.D.; Sanders, B.F. A framework for the case-specific assessment of Green Infrastructure in mitigating urban flood hazards. *Adv. Water Resour.* **2017**, *108*, 55–68. [CrossRef]
49. Zischg, A.P.; Mosimann, M.; Bernet, D.B.; Röthlisberger, V. Validation of 2D flood models with insurance claims. *J. Hydrol.* **2018**, *557*, 350–361. [CrossRef]

50. Mannina, G.; Butler, D.; Benedetti, L.; Deletic, A.; Fowdar, H.; Fu, G.; Kleidorfer, M.; McCarthy, D.T.; Mikkelsen, P.S.; Rauch, W.; et al. Greenhouse gas emissions from integrated urban drainage systems: Where do we stand? *J. Hydrol.* **2018**, *559*, 307–314. [CrossRef]
51. Bevilacqua, P.; Mazzeo, D.; Bruno, R.; Arcuri, N. Surface temperature analysis of an extensive green roof for the mitigation of urban heat island in southern Mediterranean climate. *Energy Build.* **2017**, *150*, 318–327. [CrossRef]
52. Liu, L.; Jensen, M.B. Green infrastructure for sustainable urban water management: Practices of five forerunner cities. *Cities* **2018**, *74*, 126–133. [CrossRef]
53. Di Matteo, M.; Maier, H.R.; Dandy, G.C. Many-objective portfolio optimization approach for stormwater management project selection encouraging decision maker buy-in. *Environ. Model. Softw.* **2019**, *111*, 340–355. [CrossRef]
54. Geng, R.; Yin, P.; Gong, Q.; Wang, X.; Sharpley, A.N. BMP Optimization to Improve the Economic Viability of Farms in the Upper Watershed of Miyun Reservoir, Beijing, China. *Water* **2017**, *9*, 633. [CrossRef]
55. Li, N.; Qin, C.; Du, P. Optimization of China Sponge City Design: The Case of Lincang Technology Innovation Park. *Water* **2018**, *10*, 1189. [CrossRef]
56. Meerow, S.; Newell, J.P. Spatial planning for multifunctional green infrastructure: Growing resilience in Detroit. *Landsc. Urban Plan.* **2017**, *159*, 62–75. [CrossRef]
57. Barbati, A.; Corona, P.; Salvati, L.; Gasparella, L. Natural forest expansion into suburban countryside: Gained ground for a green infrastructure? *Urban For. Urban Green.* **2013**, *12*, 36–43. [CrossRef]
58. Radinja, M.; Comas, J.; Corominas, L.; Atanasova, N. Assessing stormwater control measures using modelling and a multi-criteria approach. *J. Environ. Manag.* **2019**, *243*, 257–268. [CrossRef]
59. Tzoulas, K.; Korpela, K.; Venn, S.; Yli-Pelkonen, V.; Kaźmierczak, A.; Niemelä, J.; James, P. Promoting ecosystem and human health in urban areas using Green Infrastructure: A literature review. *Landsc. Urban Plan.* **2007**, *81*, 167–178. [CrossRef]
60. Navarrete-Hernandez, P.; Laffan, K. A greener urban environment: Designing green infrastructure interventions to promote citizens' subjective wellbeing. *Landsc. Urban Plan.* **2019**, *191*, 103618. [CrossRef]
61. Casado-Arzuaga, I.; Onaindia, M.; Madariaga, I.; Verburg, P.H. Mapping recreation and aesthetic value of ecosystems in the Bilbao Metropolitan Greenbelt (northern Spain) to support landscape planning. *Landsc. Ecol.* **2014**, *29*, 1393–1405. [CrossRef]
62. Tomalty, R.; Komorowski, B.; Doiron, D. *The Monetary Value of the Soft Benefits of Green Roofs, Final Report*; Canada Mortgage and Housing Corporation: Ottawa, ON, Canada, 2010.
63. Wilson, C.E.; Hunt, W.F.; Winston, R.J.; Smith, P. Comparison of runoff quality and quantity from a commercial low-impact and conventional development in Raleigh, North Carolina. *J. Environ. Eng.* **2015**, *141*, 5014005. [CrossRef]
64. Lee, J.G.; Selvakumar, A.; Alvi, K.; Riverson, J.; Zhen, J.X.; Shoemaker, L.; Lai, F.-H. A watershed-scale design optimization model for stormwater best management practices. *Environ. Model. Softw.* **2012**, *37*, 6–18. [CrossRef]
65. Zhu, L.; Qin, C.; Zhu, A.; Liu, J.; Wu, H. Effects of Different Spatial Configuration Units for the Spatial Optimization of Watershed Best Management Practice Scenarios. *Water* **2019**, *11*, 262. [CrossRef]
66. Cibin, R.; Chaubey, I. A computationally efficient approach for watershed scale spatial optimization. *Environ. Model. Softw.* **2015**, *66*, 1–11. [CrossRef]
67. Liu, Y.; Cibin, R.; Bralts, V.F.; Chaubey, I.; Bowling, L.C.; Engel, B.A. Optimal selection and placement of BMPs and LID practices with a rainfall-runoff model. *Environ. Model. Softw.* **2016**, *80*, 281–296. [CrossRef]
68. Liu, Y.; Engel, B.A.; Flanagan, D.C.; Gitau, M.W.; McMillan, S.K.; Chaubey, I. A review on effectiveness of best management practices in improving hydrology and water quality: Needs and opportunities. *Sci. Total Environ.* **2017**, *601–602*, 580–593. [CrossRef]
69. Sun, Y.; Tong, S.; Yang, Y.J. Modeling the cost-effectiveness of stormwater best management practices in an urban watershed in Las Vegas Valley. *Appl. Geogr.* **2016**, *76*, 49–61. [CrossRef]
70. Xu, T.; Li, K.; Engel, B.A.; Jia, H.; Leng, L.; Sun, Z.; Yu, S.L. Optimal adaptation pathway for sustainable low impact development planning under deep uncertainty of climate change: A greedy strategy. *J. Environ. Manag.* **2019**, *248*, 109280. [CrossRef]
71. Zhang, Z.; Miao, Y.; Li, J.; Liu, D.; Fang, X. Improvement effect of rainfall source control facilities on urban drainage capacity in different regions of China. *J. Hydrol.* **2019**, *579*, 124127. [CrossRef]

72. Xia, J.; Zhang, Y.; Xiong, L.; He, S.; Wang, L.; Yu, Z. Opportunities and challenges of the Sponge City construction related to urban water issues in China. *Sci. China Earth Sci.* **2017**, *60*, 652–658. [CrossRef]
73. Cohen, M.J.; Brown, M.T. A model examining hierarchical wetland networks for watershed stormwater management. *Ecol. Model.* **2007**, *201*, 179–193. [CrossRef]
74. Latifi, M.; Rakhshandehroo, G.; Nikoo, M.R.; Sadegh, M. A game theoretical low impact development optimization model for urban storm water management. *J. Clean. Prod.* **2019**, *241*, 118323. [CrossRef]
75. Cano, O.M.; Barkdoll, B.D. Multiobjective, Socioeconomic, Boundary-Emanating, Nearest Distance Algorithm for Stormwater Low-Impact BMP Selection and Placement. *J. Water Resour. Plan. Manag.* **2017**, *143*, 1–9. [CrossRef]
76. Aminjavaheri, S.M.; Nazif, S. Determining the robust optimal set of BMPs for urban runoff management in data-poor catchments. *J. Environ. Plan. Manag.* **2017**, *61*, 1180–1203. [CrossRef]
77. Azari, B.; Tabesh, M. Optimal Design of Stormwater Collection Networks Considering Hydraulic Performance and BMPs. *Int. J. Environ. Res.* **2018**, *12*, 585–596. [CrossRef]
78. Xu, C.; Tang, T.; Jia, H.; Xu, M.; Xu, T.; Liu, Z.; Long, Y.; Zhang, R. Benefits of coupled green and grey infrastructure systems: Evidence based on analytic hierarchy process and life cycle costing. *Resour. Conserv. Recycl.* **2019**, *151*, 104478. [CrossRef]
79. Maier, H.R.; Kapelan, Z.; Kasprzyk, J.; Kollat, J.; Matott, L.; Cunha, M.; Dandy, G.; Gibbs, M.S.; Keedwell, E.; Marchi, A.; et al. Evolutionary algorithms and other metaheuristics in water resources: Current status, research challenges and future directions. *Environ. Model. Softw.* **2014**, *62*, 271–299. [CrossRef]
80. Yang, G.; Best, E.P.H. Spatial optimization of watershed management practices for nitrogen load reduction using a modeling-optimization framework. *J. Environ. Manag.* **2015**, *16*, 252–260. [CrossRef]
81. Macro, K.; Matott, L.S.; Rabideau, A.; Ghodsi, S.H.; Zhu, Z. OSTRICH-SWMM: A New Multi-Objective Optimization Tool for Green Infrastructure Planning with SWMM. *Environ. Model. Softw.* **2018**, *113*, 42–47. [CrossRef]
82. Mao, X.; Jia, H.; Yu, S.L. Assessing the ecological benefits of aggregate LID-BMPs through modelling. *Ecol. Model.* **2017**, *353*, 139–149. [CrossRef]
83. Baek, S.; Choi, D.; Jung, J.; Lee, H.-J.; Lee, H.; Yoon, K.-S.; Cho, K.H. Optimizing Low Impact Development (LID) for Stormwater Runoff Treatment in Urban Area, Korea: Experimental and Modeling Approach. *Water Res.* **2015**, *86*, 122–131. [CrossRef]
84. Montaseri, M.; Hesami Afshar, M.; Bozorg-Haddad, O. Development of Simulation-Optimization Model (MUSIC-GA) for Urban Stormwater Management. *Water Resour. Manag.* **2015**, *29*, 4649–4665. [CrossRef]
85. Jayasooriya, V.M.; Ng, A.W.M.; Muthukumaran, S.; Perera, B.J.C. Optimal Sizing of Green Infrastructure Treatment Trains for Stormwater Management. *Water Resour. Manag.* **2016**, *30*, 5407–5420. [CrossRef]
86. Liu, Y.; Theller, L.O.; Pijanowski, B.C.; Engel, B. Optimal selection and placement of green infrastructure to reduce impacts of land use change and climate change on hydrology and water quality: An application to the Trail Creek Watershed, Indiana. *Sci. Total Environ.* **2016**, *553*, 149–163. [CrossRef] [PubMed]
87. Sebti, A.; Fuamba, M.; Bennis, S. Optimization Model for BMP Selection and Placement in a Combined Sewer. *J. Water Resour. Plan. Manag.* **2016**, *142*, 4015068. [CrossRef]
88. Di Matteo, M.; Dandy, G.C.; Maier, H.R. A multi-stakeholder portfolio optimization framework applied to stormwater best management practice (BMP) selection. *Environ. Model. Softw.* **2017**, *97*, 16–31. [CrossRef]
89. Fan, R.; Tong, S.T.Y.; Lee, J.G. Determining the Optimal BMP Arrangement under Current and Future Climate Regimes: Case Study. *J. Water Resour. Plan. Manag.* **2017**, *143*, 5017009. [CrossRef]
90. Giacomoni, M.H.; Joseph, J. Multi-Objective Evolutionary Optimization and Monte Carlo Simulation for Placement of Low Impact Development in the Catchment Scale. *J. Water Resour. Plan. Manag.* **2017**, *143*, 4017053. [CrossRef]
91. Liu, Y.; Engel, B.A.; Collingsworth, P.D.; Pijanowski, B.C. Optimal implementation of green infrastructure practices to minimize influences of land use change and climate change on hydrology and water quality: Case study in Spy Run Creek watershed, Indiana. *Sci. Total Environ.* **2017**, *601–602*, 1400–1411. [CrossRef]
92. Li, Y.; Ye, Q.; Liu, A.; Meng, F.; Zhang, W.; Xiong, W.; Wang, P.; Wang, C. Seeking urbanization security and sustainability: Multi-objective optimization of rainwater harvesting systems in China. *J. Hydrol.* **2017**, *550*, 42–53. [CrossRef]
93. Wang, M.; Sun, Y.; Sweetapple, C. Optimization of storage tank locations in an urban stormwater drainage system using a two-stage approach. *J. Environ. Manag.* **2017**, *204*, 31–38. [CrossRef]

94. Xu, T.; Jia, H.; Wang, Z.; Mao, X. SWMM-based methodology for block-scale LID-BMPs planning based on site-scale multi-objective optimization: A case study in Tianjin. *Front. Environ. Sci. Eng.* **2017**, *11*, 1. [CrossRef]
95. Dai, C.; Qin, X.S.; Tan, Q.; Guo, H. Optimizing best management practices for nutrient pollution control in a lake watershed under uncertainty. *Ecol. Indic.* **2018**, *92*, 288–300. [CrossRef]
96. Eckart, K.; Mcphee, Z.; Bolisetti, T. Multiobjective Optimization of Low Impact Development Stormwater Controls. *J. Hydrol.* **2018**, *562*, 564–576. [CrossRef]
97. Jayasooriya, V.M.; Muthukumaran, S.; Ng, A.W.M.; Perera, B.J.C. Multi Criteria Decision Making in Selecting Stormwater Management Green Infrastructure for Industrial areas Part 2: A Case Study with TOPSIS. *Water Resour. Manag.* **2018**, *32*, 4297–4312. [CrossRef]
98. Li, Y.; Huang, Y.; Ye, Q.; Zhang, W.; Meng, F.; Zhang, S. Multi-objective optimization integrated with life cycle assessment for rainwater harvesting systems. *J. Hydrol.* **2018**, *558*, 659–666. [CrossRef]
99. Xu, T.; Engel, B.A.; Shi, X.; Leng, L.; Jia, H.; Yu, S.L.; Liu, Y. Marginal-cost-based greedy strategy (MCGS): Fast and reliable optimization of low impact development (LID) layout. *Sci. Total Environ.* **2018**, *640–641*, 570–580. [CrossRef]
100. Yang, Y.; Chui, T.F.M. Optimizing surface and contributing areas of bioretention cells for stormwater runoff quality and quantity management. *J. Environ. Manag.* **2018**, *206*, 1090–1103. [CrossRef]
101. Alamdari, N.; David, J.S. A multiobjective simulation-optimization tool for assisting in urban watershed restoration planning. *J. Clean. Prod.* **2019**, *213*, 2505–2522. [CrossRef]
102. Helmi, N.R.; Verbeiren, B.; Mijic, A.; Van Griensven, A.; Bauwens, W. Developing a modeling tool to allocate Low Impact Development practices in a cost-optimized method. *J. Hydrol.* **2019**, *573*, 98–108. [CrossRef]
103. Liu, G.; Chen, L.; Shen, Z.; Xiao, Y.; Wei, G. A fast and robust simulation-optimization methodology for stormwater quality management. *J. Hydrol.* **2019**, *576*, 520–527. [CrossRef]
104. Luan, B.; Yin, R.; Xu, P.; Wang, X.; Yang, X.; Zhang, L.; Tang, X. Evaluating Green Stormwater Infrastructure strategies efficiencies in a rapidly urbanizing catchment using SWMM-based TOPSIS. *J. Clean. Prod.* **2019**, *223*, 680–691. [CrossRef]
105. Torres, M.N.; Fontecha, J.E.; Zhu, Z.; Walteros, J.L.; Rodríguez, J.P. A participatory approach based on stochastic optimization for the spatial allocation of Sustainable Urban Drainage Systems for rainwater harvesting. *Environ. Model. Softw.* **2019**, *123*, 104532. [CrossRef]
106. Wang, M.; Wang, Y.; Gao, X.; Sweetapple, C. Combination and placement of sustainable drainage system devices based on zero-one integer programming and schemes sampling. *J. Environ. Manag.* **2019**, *238*, 59–63. [CrossRef] [PubMed]
107. Ghodsi, S.H.; Zahmatkesh, Z.; Goharian, E.; Kerachian, R.; Zhu, Z. Optimal Design of Low Impact Development Practices in Response to Climate Change. *J. Hydrol.* **2019**, *580*, 124266. [CrossRef]
108. Geng, R.; Yin, P.; Sharpley, A.N. A coupled model system to optimize the best management practices for nonpoint source pollution control. *J. Clean. Prod.* **2019**, *220*, 581–592. [CrossRef]
109. Hansen, R.; Olafsson, A.S.; van der Jagt, A.P.N.; Rall, E.; Pauleit, S. Planning multifunctional green infrastructure for compact cities: What is the state of practice? *Ecol. Indic.* **2019**, *96*, 99–110. [CrossRef]
110. Wolch, J.R.; Byrne, J.; Newell, J.P. Urban green space, public health, and environmental justice: The challenge of making cities 'just green enough'. *Landsc. Urban Plan.* **2014**, *125*, 234–244. [CrossRef]
111. Zuo, J.; Pullen, S.; Rameezdeen, R.; Bennetts, H.; Wang, Y.; Mao, G.; Zhou, Z.; Du, H.; Duan, H. Green building evaluation from a life-cycle perspective in Australia: A critical review. *Renew. Sustain. Energy Rev.* **2017**, *70*, 358–368. [CrossRef]
112. Hung, F.; Hobbs, B.F. How can learning-by-doing improve decisions in stormwater management? A Bayesian-based optimization model for planning urban green infrastructure investments. *Environ. Model. Softw.* **2019**, *113*, 59–72. [CrossRef]
113. Kwakkel, J.H.; Haasnoot, M.; Walker, W.E. Comparing Robust Decision-Making and Dynamic Adaptive Policy Pathways for model-based decision support under deep uncertainty. *Environ. Model. Softw.* **2016**, *86*, 168–183. [CrossRef]
114. Maier, H.R.; Guillaume, J.H.A.; van Delden, H.; Riddell, G.; Haasnoot, M.; Kwakkel, J.H. An uncertain future, deep uncertainty, scenarios, robustness and adaptation: How do they fit together? *Environ. Model. Softw.* **2016**, *81*, 154–164. [CrossRef]

115. Casal-Campos, A.; Fu, G.; Butler, D.; Moore, A. An Integrated Environmental Assessment of Green and Gray Infrastructure Strategies for Robust Decision Making. *Environ. Sci. Technol.* **2015**, *49*, 8307–8314. [CrossRef] [PubMed]
116. Butler, D.; Ward, S.; Sweetapple, C.; Astaraie-Imani, M.; Diao, K.; Farmani, R.; Fu, G. Reliable, resilient and sustainable water management: The Safe & SuRe approach. *Glob Chall.* **2017**, *1*, 63–77. [PubMed]
117. Bakhshipour, A.E.; Dittmer, U.; Haghighi, A.; Nowak, W. Hybrid green-blue-gray decentralized urban drainage systems design, a simulation-optimization framework. *J. Environ. Manag.* **2019**, *249*, 109364. [CrossRef] [PubMed]
118. Alves, A.; Gersonius, B.; Sanchez, A.; Vojinovic, Z.; Kapelan, Z. Multi-criteria Approach for Selection of Green and Grey Infrastructure to Reduce Flood Risk and Increase CO-benefits. *Water Resour. Manag.* **2018**, *32*, 2505–2522. [CrossRef]
119. Casal-Campos, A.; Sadr, S.M.K.; Fu, G.; Butler, D. Reliable, Resilient and Sustainable Urban Drainage Systems: An Analysis of Robustness under Deep Uncertainty. *Environ. Sci. Technol.* **2018**, *52*, 9008–9021. [CrossRef]