

## Review

# Benefits, Inconveniences, and Facilities of the Application of Rain Gardens in Urban Spaces from the Perspective of Climate Change—A Review

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**Abstract:** The need to support existing sewage systems is obvious due to the noticeable consequences of climate change, such as extreme rainfall, which is causing more urban flooding. It is believed that these phenomena will intensify in the long-term, and that sewage systems will be overloaded with stormwater. Consequently, cities will need more opportunities to protect themselves from flooding. Moreover, longer periods of drought will increase the temperatures in towns. The use of blue and green infrastructure is being used to adapt to climate change and to limit its effects in cities. However, it is important not to apply these solutions indiscriminately. They have obvious advantages, but are also limited in their uses. Facilities are also being developed for the design and construction of green infrastructure. This article presents the benefits of using rain gardens in urban spaces and in relation to other forms of blue–green infrastructure; it also explored the problems that may occur while using them. More important facilitations in the implementation of rain gardens into urban fabrics are discussed, particularly in the context of the existing inconveniences. A holistic approach to the issue was applied addressing technical, economic, environmental, and social aspects.

**Keywords:** raingarden; blue and green infrastructure; LID; rainwater; stormwater; sewerage; climate change; bioretention



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## 1. Introduction

### 1.1. Climate Change Effects, Prediction and Climate Models

One of the effects of climate change involves the more frequent occurrences of extreme weather, including rain (several days of intense pouring rain or short heavy (torrential) rain) and lingering periods of drought. Therefore, it is essential to have daily precipitation forecasts/outlooks in a given catchment area. The annual rainfall in a given area, as well as knowledge about prolonged periods with no precipitation, are also important. Regarding climate models—there are global climate models (GCMs) and regional climate models (RCMs). Global climate models can provide reliable forecasts on a scale of approximately  $1000 \times 1000$  km [1]; however, the resolutions of GCMs are not sufficient for planning adaptation measures in individual countries [2]. Therefore, downscaling and regional climate models (RCMs) are needed.

When discussing RCMs, it is worth mentioning the coordinated regional climate downscaling experiment (CORDEX) initiative. The CORDEX initiative was created to generate regional projections of climate change for all terrestrial regions across the globe; EURO-CORDEX is the European branch of this initiative [3]. The CORDEX regional climate model simulations for Europe (EURO-CORDEX) are available, e.g., on a grid with a resolution of about 12.5 km [2,4]. We should note that the EURO-CORDEX simulations take into account different greenhouse gas emission scenarios—representative concentration

pathway(s) (RCP)—relating to different values of radiative forcings (including  $8.5 \text{ W/m}^2$ —RCP8.5) [3]. Under the aforementioned EURO-CORDEX initiative, regional climate model simulation ensembles are created, and the results of models from the EURO-CORDEX repository consist of input data that could be used for further research and studies [2].

For example, for Kraków (a major city in Poland), as part of the city's plans to adapt to climate change [5], regarding the description of the main climatic threats and derivatives for the city, the analyzed results of the EURO-CORDEX bundles, concerning the sum of the annual rainfall, indicate an “uptrend”. The annual sum of precipitation will increase from an average of 713 mm in 2026–2035 to an average of 737.5 mm in 2046–2055 [5]. In the same study (forecasting extreme rainfall events), an upward trend was indicated concerning the number of days with precipitation above 10 mm/d per year. The index values were calculated on the basis of data from EURO-CORDEX. The number of days with precipitation above 10 mm/d will increase from an average of 17.9 days in 2026–2035 to an average of 19 days in 2045–2055 [5]. Regarding the number of days with precipitation above 20 mm/d, the EURO-CORDEX results also show an upward trend [5]. On the other hand, in the case of forecasts related to the risk of drought, the longest period of the year without rainfall shows neither an upward nor a downward trend, and the differences are insignificant [5]. The precipitation phenomenon that occurred in Kraków on 5 August, 2021, can be cited as a supplement to these projections. According to data from the Institute of Meteorology and Water Management—National Research Institute, on that day, a 103 mm high rainfall was recorded at the Botanical Garden measurement station; according to unverified (but probable data), it was the highest recorded rainfall in the center of Kraków in 126 years [6,7]. Such a rainfall, corresponding to a two-month average precipitation norm in August [6], confirms the occurrence of **weather anomalies and a need for the quickest way for cities to adapt to climate change.**

### 1.2. Climate Change Effects, Mitigation and the Aim of the Work

The described forecasted effects of climate change (for one city), along with data on rainfall phenomenon in August 2021, may confirm that the problems with rainwater management in cities will increase. It is necessary to take multilateral measures to limit the **consequences of climate change in cities, such as urban flooding, inundations, and droughts.** At this stage, only one-way actions (i.e., investments only in gray or only in blue and green infrastructure) might be insufficient, which is why it is important to have complete and transdisciplinary knowledge regarding the solutions that could be applied, with a comprehensive approach to the subject, i.e., not solely limited to, for example, only the advantages and disadvantages, but also to the possibility of counteracting (or eliminating) the inconveniences. Regarding blue–green infrastructure, **rain gardens are simple and cheap solutions and are relatively effective in terms of rainwater management. The ease of implementing these gardens into urban tissue is extremely important.** The available area of the plot is not a special limitation, one should only consider that it significantly determines the efficiency of the garden. **It is important that it is much easier to set up a rain garden on the ground than a green roof on an existing building.** The advantages: **there is a low probability of causing a negative impact to the building, and both residents and city authorities have many areas available for this purpose.** For these reasons, one can see huge potential in rain gardens, in terms of spreading blue–green infrastructure in urban areas. In turn, **the greater the number of rain gardens, the greater their role in rainwater management and adapting to climate change/its effects.**

There are many scientific papers on rain gardens, but most deal with one topic or a group of issues. Others, in turn, are limited to research typically carried out at one location, or at one—or a few—garden structure(s). This generates large differences in the reported efficiencies. However, the number of scientific papers on rain gardens, with a holistic approach, taking into account technical, economic, and social aspects, is insufficient.

**As with any solution, there are both advantages and inconveniences with rain gardens. It is critical to be aware about the positive and negative sides of this solution.** In this

case, it is possible to look for answers to the questions concerning how to eliminate the inconveniences, what other solutions could be used, or what tools and actions could be taken to grow rain gardens in urban tissue. Many works compare the advantages and disadvantages of rain gardens, but rarely in the context of facilitations—helping to solve problems related to the design, construction, and operation of these gardens. They also rarely consider all of the possible pros and cons.

Comprehensive knowledge about the benefits and inconveniences of implementing and maintaining rain gardens, as well as the facilities, is of great importance. This will make it easier for city managers to develop strategies to implement blue and green infrastructure. This will also draw attention to the need to include rain gardens as part of the considered solutions to adapt to climate change. Finally, this will help facilitate the selections for investors or decision-makers (i.e., about the most suitable solutions). Taking social considerations into account could help implement and disseminate these solutions. In turn, for scientists, such knowledge indicates (possible and necessary) directions for further work. Therefore, this knowledge is needed by private owners, state/local government bodies, and scientists.

For these reasons, the aim of this article was to analyze and present the benefits, inconveniences, and facilitations regarding the implementation of rain gardens in urbanized areas.

## 2. Rain Gardens: Definitions and Nomenclature; Classification: Similarities and Differences

### 2.1. Definitions and Nomenclature

Many definitions of rain gardens can be found in scientific (and industry) literature, as well as on the internet; they are usually in accordance, but they are expressed in slightly different ways. They sometimes differ regarding the degree of detail in the definition, or they vary in the scope of the solution adopted, such as with rain gardens, e.g., rain gardens made in containers are not always taken into account. Dissimilarities also appear regarding the assignment of rain gardens, within the classification of rainwater management methods. There are differences in the divisions of rain gardens. Alternative names for rain gardens also appear.

Rain gardens are included in localized stormwater control measures (SCMs) [8]. One of the simpler definitions of a rain garden specifies it as a depressed area in a landscape with planted grass and flowering perennials that collect rainwater from roofs, driveways, or streets, allowing it to soak into the ground [9]. Similar explanations can be found in [10]. According to the authors, these are relatively small depressions in the ground that can act as points of water infiltration from the roof or from another “clean” surface, i.e., water with a low level of pollution. According to [11], rain gardens are shallow, constructed depressions, planted with deeply rooted native plants and grass, and the aim of the strategic location is to capture runoff from hard surfaces, such as driveways, parking lots, sidewalks, and streets. The authors of [12] define rain gardens as small, shallow, and sunken areas of planting that collect rainwater from roofs, streets, and sidewalks. The authors of [13] depict a rain garden as a specially-created green area that uses selected plant species to increase the retention of rainwater. Often, the purpose of its construction is to take the runoff from roads, walkways, rooftops, and other surfaces, with limited retention during heavy rainfall; it can be designed directly in the ground or in containers of different capacities [13]. The authors of [14] describe rain gardens as gardens of native shrubs, perennials, and flowers planted in small depressions, usually formed on natural slopes. These are solutions designed to temporarily hold and soak in rainwater that runoff from roofs, driveways, terraces, and lawns [14]. We should note that, according to this source, rain gardens are not water gardens—they remain dry most of the time. Rain gardens are natural or artificial depressions that temporarily retain water and allow rainwater to soak into the ground at the site of rainfall [15]. In turn, one of the more comprehensive definitions [16] describes rain gardens as landscape depressions consisting of several layers of filtration media, overflow,

and various types of vegetation, as well as optional underdrains. Another definition [17] specifies that rain gardens are depressed areas with vegetation, engineered soil mixes (containing different layers), and (optional) sand or gravel drainage beds that meet the requirements for water reuse.

There are also definitions that primarily consider the purposes and benefits of using rain gardens, rather than their construction. Rain gardens are effective low impact development (LID) practices that are used in residential areas to capture stormwater runoff, to recharge groundwater by infiltration, and to remove pollutants from the water before it enters local streams [8]. Phosphorus is an example of a pollutant that is removed [8].

The above comparisons (of the selected definitions of rain gardens) confirm that rain gardens are similar but are formulated with slightly different wordings. Sometimes they vary in the degree of detail. However, full compliance is not found in every aspect of rain gardens.

There are also differences with the nomenclature itself. A rain garden with a more complex structure, equipped with a drainage system and altered soil, is often referred to as bioretention [9]. On the other hand, the terms rain garden, bioretention, bioretention system, and bioretention cells are used interchangeably [16]. Moreover, rain gardens are also known as bioretention cells [12,17].

## 2.2. Classification of Rain Gardens

As mentioned earlier, there are differences in the classification of rain gardens among rainwater management methods. For example, they are classified under sustainable rainwater management systems as an infiltration with surface retention [15,18]; it is a way to use rainwater to shape and supply local landscape elements [19]. On the other hand, the authors of [20] count rain gardens as bioretention areas. They are also classified as localized SCMs [8]. Rain gardens are also referred to as LID facilities [16] or LID practices [8,16], as well as rainwater management practices [16].

Regarding the division of rain gardens, there are also some differences in the analyzed literature sources. Rain gardens are divided into gardens in the ground and gardens in containers; in this matter, there is general agreement, although some sources do not take into account (or do not specifically articulate in their definitions) the possibility of creating gardens in containers or pots. Regarding gardens built in the ground, there are different divisions and different nomenclature. There is a partition into so-called “dry rain gardens” (in the case of a permeable subsoil) and so-called “wet rain gardens” (in the case of impermeable subsoil) [21]. However, according to [14], as mentioned earlier, rain gardens remain dry most of the time. On the other hand, rain gardens in the ground include infiltration gardens and foil-lined gardens [22]. These gardens can be divided into gardens with full infiltration, partial infiltration, and no infiltration, depending on the ability to infiltrate the land in which they are made [23]. Moreover, the authors of [24] separate rain gardens into two types: with infiltration and with filtration.

Considering the discussed differences, we can conclude that there is a need to standardize the theoretical basis for rain gardens, especially in terms of the division and classification of rain gardens.

## 3. Benefits of Using Rain Gardens

### 3.1. A Holistic Approach to the Issue

Implementing blue–green infrastructure solutions into urban tissue is associated with a number of benefits to the urban environment. It is no different in the case of rain gardens. They should be classified as multifunctional solutions. There are technical, operational, and ecological benefits, as well as social and health profits resulting from the use of rain gardens in the city. Their aesthetic qualities (as well as potential financial savings) can be added, but open space must be available. It is important to consider all of the benefits of using them when considering the various options, when making decisions concerning the planning of a city, and in city spatial management. Therefore, it is important to take a holistic approach

to this issue. Figure 1 shows a diagram that illustrates the comprehensive approach to the benefits of implementing rain gardens in a city. A similar approach to profits from stormwater infrastructure was adopted in one of the tools of the American Environmental Protection Agency [25]. This stormwater online tool (named CLASIC) as part of its output provides information about performance (volume reduction and pollutant load reduction), and assesses the value of co-benefits, regarding the environmental, social, and financial gains [25].



**Figure 1.** Holistic approach to the advantages of using rain gardens in an urban space—the main types of benefits.

### 3.2. Participation in Rainwater Management

The most important benefit concerning the use of rain gardens involves their participation in the management of rainwater. Hence, the adjective “rain” appears in the name. Rain gardens are important alternative methods of rainwater management. They are also classified as devices used for sustainable rainwater management [15]. It is extremely important that they manage rainfall where it occurs. “Fall down”/Downpipes of rainwater systems in buildings can be disconnected from the sewage system and their outflow could then be directed to rain gardens.

The advantages, in this respect, include decreasing the volume of rainwater runoff from the catchment area (on the micro and macro scale—property and district/city) and a reduction (and delay) of the peak water flows in the sewage system, which is of particular importance in preventing hydraulic overload of a sewage network. For example, the bioretention cells receiving outflow from one parking lot, assessed for efficiency, lowered the peak flow rates leaving the parking lot by 99% [26]. The research conducted by Razaei et al. [27], with the use of the model developed by the United States Environmental Protection Agency’s Storm Water Management Model (US EPA SWMM) program for the



simulation of LID techniques (with the use of rain gardens) indicates that a small change catchment parameters, such as imperviousness, the depression storage, or the depth of depression storage, will significantly change the simulated peak flow. Rain gardens allow 30% more water to soak compared to traditional lawns, according to [14]; according to [11], the value of this increase even reaches 40%. The percentage reduction in the volume of rainwater drained from the catchment area through the use of rain gardens depends on the intensity of the precipitation and its duration as well as the construction of a rain garden; hence, there are large differences in the values reported in the literature, such as the overall percentage reduction in the runoff volume. The aforementioned studies [27] indicate that even small changes in the imperviousness, depression storage, or the depth of depression storage will significantly change, in addition to the peak flow and the simulated runoff.

The effectiveness of reducing runoff volume has been documented in individual studies [28] and reviews or introductions to various scientific papers [16,17]. According to the [16], the overall percentage of runoff volume reduction is in the range of 50 to 98% for various studies, although these works were performed in the United States. According to the [17], the reduction of runoff volume using rain gardens is in the range of 23 to 97%; that work refers to research conducted in the United States, Australia, China, Malaysia, and Turkey. Therefore, it can be concluded that the use of such solutions reduces (at least slightly) the probability of overloading the rainwater or combined sewage system—although this applies to a situation in which rain gardens would be introduced in a given urban catchment on a large-scale. In the case of one plot, the implementation of such a solution reduces the volume of the outflow from the property and reduces the risk of flooding the property [11,17,29], provided that the garden is located in an appropriate place. This can be confirmed by the study in which the investigated rain gardens were considered practical, in terms of reducing the risk of rainwater-related disasters and increasing resistance to short-term heavy rain [17]. Concerning the role of rainwater management—rain gardens reduce the effects of climate change in the city.

### 3.3. Economic Issues

Reducing the risk of property flooding could also be included in the prevention of possible financial losses caused by inundating factors, i.e., the elimination of costs related to the liquidation of damages caused by flooding with rainwater.

When discussing the potential economic benefits of using rain gardens, there are fee reductions or rebates that owners may obtain from water service companies (e.g., the WaterWise Rainscape Rebate program in Austin, US [30]), or co-funding for the construction (e.g., the program “My Water” in Poland [31]). The application of such a solution may reduce the fees associated with draining rainwater to the sewage system, or fees for lost retention, depending on the regulations of a given country. The use of rain gardens is also associated with economic benefits in the form of potential savings. The arrangement of greenery around the house in the form of a rain garden allows the use of rainwater for irrigation of vegetation in the rain garden, reducing the use of tap water to water greenery [29]. In turn, the reduced demand for tap water includes lower bills and savings on water bills. Economic issues related to green infrastructure, including rain gardens, were analyzed in [32], where, inter alia, the evaluation of financial profitability was according to the rate of return and the payback period. Rain gardens enhance the value of a property, according to [11].

The positive role of rain gardens in rainwater management is not solely limited to generating benefits—in terms of the operation of sewage systems and potential savings or profits for owners—there is also the possibility of using rainwater purified by these gardens (e.g., solutions in drainage beds). The authors of [17] indicate recycling and re-using part of the water purified by the rain garden.

### 3.4. Role in Water Protection

The environmental gains in terms of water protection are also directly related to the management of rainwater by rain gardens. When listing the benefits assigned to water management in the catchment area, some rain gardens (the so-called “dry” ones) recharge groundwater [11,29,33]. Rain gardens affect not only the amount of rainwater, but also the quality. One of the main benefits of LID solutions is the possibility of reducing water pollution; thus, contributing to the regulation of the biogeochemical cycle [34].

LID practices, such as rain gardens, use the chemical, biological, and physical properties of the soil, but also of plants and microbes, to remove pollutants from rainwater [35]. These solutions purify rainwater by filtering pollutants [29]. Purification of rainwater in rain gardens take place by means of sedimentation and filtration by the soil, plant uptake, chemical reactions in the soil, and biological degradation in the root zones [35]. Their role is to protect surface waters against contaminated rainwater runoff entering them [11,36]. They also protect groundwater [17]. These gardens effectively remove up to 90% of nutrients and chemicals, as well as up to 80% of sediments, according to [14]. The removal of pollutants, such as suspended solids (total suspended solids), nitrogen, and phosphorus (total nitrogen and total phosphorus), as well as organic substances, expressed as chemical oxygen demand (COD) by rain gardens, was scientifically documented [16,17,28]. There are also reports [37,38] that bioretention cells can remove bacteria. The studies confirmed the reduction of fecal coliform and *E. coli* bacteria [34,37,38]. Research on the effectiveness of bioretention, in terms of heavy metal removal, has also confirmed that bioretention cells can remove some metal (zinc, lead, and copper) [37].

### 3.5. Benefits for the Ecosystem and Biodiversity

Rain gardens provide enhancements to the local ecosystem. They attract useful insects, butterflies, and birds, because they can provide food and shelter for wildlife (including butterflies and singing birds) [9,14]. They can improve the habitat for wildlife [16]. They preserve natural vegetation [14] and biodiversity [17], and even increase biodiversity [24]. The authors of [33] mention an additional benefit—pollination.

### 3.6. Rain Gardens as Multifunctional Solutions—Benefits for Society

The benefits of using rain gardens in the city can also be considered in other “dimensions”. As community projects, rain gardens can bring neighborhoods together [39]. The presence of greenery and water are important features of health-promoting places [40]. Rain gardens can also benefit human health; their use can help to create health-promoting places [40].

The benefits of using these gardens also include improving the aesthetics of the area or providing visual amenities [16,33]. They can be planned as elements of a landscape [10].

In addition to the above-mentioned benefits, noise reduction, air quality improvement, carbon dioxide capture and storage, and local climate control or reduction of urban heat island effects can be added [17,33].

The authors of [16] suggest searching for (and selecting) such plants for bioretention that will allow communities to produce food from their rain gardens. This may open up new perspectives for these solutions in the cities of the future.

### 3.7. Other Benefits

One characteristic feature of rain gardens is that they are multi-functional. In addition to the previously mentioned benefits of their functions, i.e., in the management of rainwater in the catchment, water protection, or benefits for the ecosystem, they also have other additional benefits. The advantages of using rain gardens, instead of other, more complex solutions (such as green roofs) include a significant reduction in the time from the decision to choose the LID practice to its implementation. Rain gardens require less documentation, do not require specialized expertise or complex projects, such as green roofs (especially those introduced/planned on existing buildings). The use of heavy equipment is not always

necessary. There are advantages for investors, i.e., in arranging rain gardens on properties when applying for certificates under multi-criteria assessments of building systems, e.g., the Building Research Establishment Environmental Assessment Method (BREEAM) or the Leadership in Energy and Environmental Design (LEED); these possibilities can also be classified as facilitations of the implementation of these gardens to cities. "Points" can be obtained for improving the ecology of a site, providing solutions for runoff contamination, or rainwater management [41,42].

Profits can also be seen in reduced workloads and in the ease of maintenance of rain gardens, especially when using native plants, compared to other LID solutions. They also contribute to reducing erosion in the area [16].

#### 4. Inconveniences in the Application of Rain Gardens

##### 4.1. Adopted Assumptions

It was assumed that, as the inconveniences of using rain gardens were discussed, the weaknesses and limitations in their use, as well as the nuisances and problems that may occur when applying these LID practices. Rain gardens have few disadvantages if well designed and built [43]. Hence, the main emphasis should be placed on their proper design and implementation, which will significantly reduce the inconvenience.

##### 4.2. Land Area Demand

One of the main weaknesses involves the relatively high space requirement. There are some differences in the values of the typical surface areas required for rain gardens, depending on the source. It is usually 7 to 20% of the impervious surface generating a runoff into the garden [44,45]. The same range of values (7 to 20%) was presented in [46], but the specific value depends on the percolation rate and the depth of the planned rain garden. The authors of [11] indicate that, depending on the type of soil, the garden area should be equal to 20 to 30% of the drainage area for sandy soil, and in the case of replacing the soil with rain garden mixture, and about 60% for clay soil. Similar rules are provided in [47]: 10 to 20% (slightly less) of the total drainage area for gardens located on sandy soils and 50 to 60% for gardens on very clayey soils.

The general rule is that the rain garden should constitute 5 to 10% of the catchment area [23]. In turn, according to [35], the area of rain gardens usually range from 3 to 10% of the total catchment area. Regarding the "demand" for space for gardens—their impacts on reducing the volume of rainwater may be limited due to the fact that gardens are usually small [10].

##### 4.3. Limitations of Use

It is not always possible to use a rain garden. There are some limitations here. They should not be used on properties with steep slopes [10,46], nor should they be used in areas where there is insufficient rainfall [47]. Rain gardens should also not be located in areas with high groundwater tables [47]. They are neither suitable in polluted places nor in locations above sensitive groundwater systems [10]. Gardens of this type should not be located in naturally wet places [48]. Sometimes there are formal and legal restrictions. Some regions of United States have laws that prohibit the collection and storage of rainwater for any use [48].

##### 4.4. Possible Problems at the Design and Construction Stage

Rain garden applications in the city are wide, but there are some limitations. For this reason, it is important that the rain garden is designed and constructed correctly. An improperly designed rain garden (starting from selecting the wrong place) can generate many problems and inconveniences. The same situation applies to the realization of this object. When choosing a place for a rain garden, one should focus on the distance from the building foundation, the location of the septic tanks or wells with drinking water (and the distance from them), the presence of possible underground infrastructure, as well as



the presence of tree roots [35,47–50]. At the same time, the distance between the garden and the downspouts should not be too great (greater than about 9 m) [51]. Existing land use, existing vegetation, and slope should also be taken into account [35]. The above-mentioned limitations are usually not major problems, because facilities allow for the correct garden locations (instructions on what distances from the individual elements are required [46,48,52], and the service facilitating the presence of possible underground infrastructure [53]).

In addition to the location—the depth of the garden, the selection of the layers of the garden, the selection of plants, inflow, outflow, overflow solution, as well as other technical details, such as the garden area itself, are also significant. It is essential to “make” the garden correctly. In order to eliminate the inconvenience caused by an improper garden design or its realization, a number of facilities have also been developed, which include a wide range of manuals, guides, and instructions on how to implement such investments, step-by-step, on a property.

#### 4.5. Economic Issues

The costs associated with their construction of rain gardens in a city should be discussed. They are not very high, but they are always present. The cost of implementing a rain garden varies significantly, depending on the place, type of soil, investor’s purpose, or the need for earthworks [43,54]. The area of the garden is also an important factor that influences the final cost estimate. Prices between USD 5 and 40 (or more) for a square foot of this type of garden can be expected [43]. A similar range is taken by the rain garden cost calculator, between USD 5 and 45 per square foot of garden [54]. The cost of a rain garden is influenced by many factors, including the type of soil and whether it will be replaced, the size and depth of the garden (and the associated scope of earthworks), the type of garden (with or without a drainage bed), the choice of plants, and the required materials for construction. The costs associated with the construction of the rain garden include earthworks related to the excavation and hauling of existing soil, the import of a new soil mixture for rain gardens or soil improvements, as well as the costs of purchasing materials (gravel, filter cloth, mulch, perforated pipes, overflow box) [35,52]. The highest cost in the case of rain gardens occurs when purchasing plants [55]. In terms of plant selection, the choice of a wildflower garden is one of the cheapest planting options [23].

#### 4.6. Maintenance of Rain Gardens

Rain gardens require certain treatments carried out by the owners or managers of the area, in terms of their maintenance. Landscaping and management are essential [10]. The need for management also applies to the surrounding landscape [10]. In particular, in the first period, the scope of the work and control may be inconveniences. Irrigation, inspection of the area where water enters and exits the garden for erosion (and possible repair), pruning, and removal of weeds and invasive species (if they occur) are needed [56–58].

Irrigation may be necessary during the first one to three years of operation, as well as during periods of prolonged droughts [58]. In the long-term, it is necessary to remove dead branches from shrubs and trees, and to remove dead vegetation from perennials and grass [56]. Where necessary, weeds and invasive species should be removed [56]. The thickness of the mulch layer—to keep the garden moist and to prevent weed seeds from sprouting—should be checked annually and replenished as needed [57]. The garden should also be monitored for erosion and sediment accumulation and, if necessary, appropriate measures should be taken [56,58]. It is necessary to collect rubbish from the garden area, in both the initial phase and in the long-term [23].

If the rain garden has not been properly designed or constructed, further inconveniences may appear during its operation. According to [51], a properly designed garden holds water only for about 6 h after a downpour. The authors of [47] claim that water should drain from the garden within 24 h. The authors of [24] state that, in locations where water ponds, the gardens should be designed for drawdown times no longer than 48 h.

For example, one city in the United States (Austin) recommends a drawdown time aim of no more than 2 to 3 days [24]. If this does not occur within 3 days, then problems, such as odors, mosquitoes, and possible effects of water on plant health, can occur [24]. If the garden is not working properly, it may also experience drainage problems [43]. If ponded water remains in the garden basin for more than 3 days after the end of the storm, any reduction in drainage rate by leaves, debris, or sediment build-up must be ruled out [52]. Among the unfavorable features that may occur during the operation of a rain garden, one should also mention their susceptibility to clogging, if the surrounding landscape is not managed [10].

#### 4.7. Social Problems

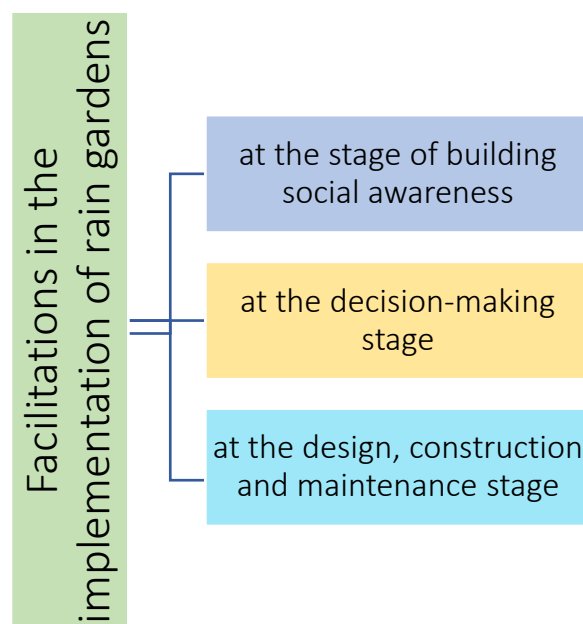
In addition to the above-mentioned inconveniences, in terms of design, construction, and operation, as well as the costs of such an investment, social problems may arise. Rain gardens can be implemented as visible community projects [39]. For this reason, proper communication with the community is extremely important. Such projects can generate neighborhood conflicts if planners and coordinators fail to take appropriate steps to obtain community support and address concerns in advance [39]. For these types of problems, facilities are developed that allow for the proper preparation of a communication plan during the implementation of the project.

### 5. Facilities for the Application of Rain Gardens

#### 5.1. Definition and Classification of Facilities

In view of the inconveniences when implementing rain gardens into urban tissue, as discussed in the previous section, there are many amenities and facilities aimed at increasing the application of rain gardens in an urban space. While the advantages and disadvantages of rain gardens are often discussed, this does not apply to a comprehensive approach to the amenities offered and created for the spread of this type of investment. All activities and tools facilitating the design, construction, and maintenance of a rain garden (including the decision to set up a rain garden by the owner himself) have been classified as facilities. Actions and tools to facilitate the implementation of rain gardens can be classified in various ways. Due to the stage of the investment, these facilities can be divided into two types: (1) facilitating the decision-making by a potential investor, i.e., the owner of the property, and (2) facilitating the design, implementation, and maintenance. What is also important is broadly understood education aimed at building awareness of climate changes in society and the need to adapt to them, which is necessary for every citizen. Such activities often start in kindergarten. For this reason, a third type exists—starting at the very beginning of an informative nature, often bringing tangible results in a much longer time perspective. These activities prepare the groundwork for future decisions on the use of rain gardens. Figure 2 presents the types of facilitations in the implementation of such solutions in cities, due to the current stage of creating a garden. Taking into account the form of the occurrence of a given facility, another classification can be introduced. The most important amenity forms include:

- Computer programs (including mobile applications);
- Special guides, manuals, and instructions;
- Workshops and training;
- Videos and webinars (instructional, training, informative);
- Websites and web pages;
- E-courses, online courses;
- Co-financing programs and rebates (etc.) solutions.



**Figure 2.** The classification of facilitations of the rain garden application in the city, depending on the implementation stage of the solution.

The above-mentioned facilitation forms can be used successfully at the stage of building awareness in society (regarding the need for blue–green infrastructure solutions) and at the stage of making decisions (when implementing a rain garden), as well as during the design, construction, and maintenance of the introduced bioretention system.

## 5.2. Computer Programs and Other Tools

### 5.2.1. Specialized Solutions

The first of the discussed groups of tools is primarily intended for specialists. Although most of these are tools available to all users, specialized knowledge is required to use them. This group includes tools used in the decision-making, design, and operation phases, as well as for scientific research and development of modifications.

An important group of tools facilitating the use of rain gardens involves computer programs dedicated to blue–green infrastructure facilities or having functions that allow for the introduction of LID practices (such as rain gardens) to the conducted analyses. The Stormwater Management Model (SWMM) program developed by the United States Environmental Protection Agency should certainly be mentioned. It is a dynamic simulation model of the rainfall–runoff, which is used to simulate the quantity and quality of runoff from urban and non-urban areas [59]. This desktop program is used for planning, analysis, and design related to rainwater runoff, as well as sanitary sewage systems and other drainage systems [59,60]. SWMM is an open source public software that can be used free of charge by users all over the world [60].

The program also includes the possibility of modeling the outflow from various forms of green infrastructure, including rain gardens (in the form of a designed soil layer without a gravel bed) and bioretention cells (with the possibility of adding a layer of gravel drainage bed). This program enables an estimation of the outflow generated by a specific rainfall event from a given catchment using a specific rain garden solution, compared with the outflow from the catchment without this form of green infrastructure. The SWMM program could be used as an aid at the initial stage (showing how the rain garden works, comparing different options, making decisions) and at the design stage, and it could assess already built rain gardens. Currently, it is often used to model the functioning of rain gardens in catchments (planned or existing), as exemplified by numerous scientific articles on this subject, including [17,27,61]. The United States is a country that is well prepared to introduce

green infrastructure to urban spaces. The United States Environmental Protection Agency has many tools and resources to facilitate the implementation of green infrastructure into urban fabric at various stages of the process (from learning to decision making and design to evaluation). Tools used to model green infrastructure, in addition to the aforementioned SWMM program, include GIWiz, CLASIC, and GIFMod.

One interesting solution is an interactive web application [62] called GIWiz. Within it, one can choose between searching for quick links and exploring the US EPA's tool and resources related to green infrastructure. When searching for quick links, the user selects a specific goal of his/her search (learn, research, design, assess), and when exploring resources, the user must answer questions (at least one), allowing for personalization of searches to his/her needs. This tool can be successfully used by both specialists and ordinary users.

Another computer program worth mentioning is a green infrastructure flexible model called GIFMod, used to build conceptual models to mainly assess the performance of urban stormwater green infrastructure [63,64]. These models make it possible to predict hydraulic efficiency and water quality [63]. The program can be used to build models of rain gardens, for which detailed instructions [65] are included among many practical examples on the program's website; see reference [66]. For information on the use of this tool to model bioretention systems, read Alikhani et al. [67]. An interesting online tool is the Community-enabled Lifecycle Analysis of Stormwater Infrastructure Costs, (CLASIC for short), which may prove particularly useful at the stage of deciding which solution to choose in the field of stormwater management in the city. The tool uses the life cycle cost (LCC) framework to conduct a feasibility study for rainwater infrastructure [25]. The output from this tool includes such components as: life cycle cost(s) (LCC), additional benefits, and efficiency (including reduction of runoff volume and reduction of pollutant load) [25,68]. Rain gardens and bioretention are among the rain infrastructure in the CLASIC tool [25]. The CLASIC tool, such as the aforementioned GIFMod and GIWiz, belongs to the toolkit to model green infrastructure of the US Environmental Protection Agency [63]. Apart from the mentioned programs for modeling LID controls, in the reviews related to this issue [34,67], various other programs, both free and commercial, designed for this purpose, are also listed. The list of LID practices modeling programs can be extended, for example, with programs such as: Model for Urban Stormwater Improvement Conceptualization (MUSIC for short), Hydrologic Engineering Center's Hydrologic Modeling System (HEC-HMS for short), Long-Term Hydrologic Impact Assessment Model (abbreviated as L-THIA-LID), and MIKE Urban/Model for Urban Sewers (abbreviated as MOUSE) [34,67].

#### 5.2.2. Solutions for Ordinary Users (Non-Specialists)

Next, we discuss a group of tools mainly intended for ordinary users (non-specialists). Solutions from this group are used at the stage of decision making, designing, building, and in the maintenance of rain gardens.

Another important solution is a mobile app, called the Rain Garden app, used for designing, creating, and maintaining rain gardens. It is available on any device with internet access, i.e., phones, tablets, and laptops [69], at an address listed as [70]. This application helps the user via the use of video tutorials, diagrams, texts, and tools to properly design, build, and maintain a rain garden (including help with the location, dimensions, and selection of plants) [69]. Another example of a very simple tool supporting the process of designing a rain garden is the calculator of rainwater runoff from the plot available on the website [57]. The only data needed are the area of the plot and the amount of precipitation in the area. The downside of the calculator is that one cannot change the input units—it is only square feet for area, inches for precipitation, and gallons for runoff volume. Another facilitation is the cost calculator available on the website [54]. It calculates the range of possible garden construction costs depending on the roof area or the area of the garden.

### 5.3. Internet Resources

Computer programs are not the only facilitations in the implementation of rain gardens in urban spaces—internet resources are also significant. There are many websites devoted entirely (or in part) to rainwater management—including rain gardens [9,10,12] or only rain gardens [29,36]. There are also numerous handbooks, manuals, fact sheets, instructions, or guides for rain gardens available on the internet, i.e., for download or viewing online [11,21,22,52,71–73]. These types of amenities are intended to support the design, construction, and maintenance of gardens, as well as facilitate communication with communities.

One interesting example is the guide in reference [39]. As the authors prepared the materials in the most accessible and comfortable way for the user, i.e., by listing the facilities for the implementation of rain gardens, one should not forget about the various types of films (instructional, recorded training transmissions—an example of which is [74], or informative), as well as webinars—available at a specific time [75,76], or which were recorded as films [77]. Online courses are important forms of e-learning education in the area of rain gardens. Examples of these types of courses about rain gardens can be found in references [29,78]. Selected portions of the online courses are free, the rest are paid.

The audiences of this “group of facilities” are mainly ordinary users, i.e., private property owners.

### 5.4. Workshops, Subsidies, and Other Programs and Actions

In addition to the wealth of internet resources, there are other measures that could help bring rain gardens into cities. These include design or educational workshops for residents, as well as programs and projects carried out by various entities. These are programs that subsidize investments in rain gardens, provide discounts, etc. It is worth mentioning the priority program, “My Water”, carried out in Poland to alleviate the effects of drought, financed by the National Fund for Environmental Protection and Water Management. The program implementation years are from 2020 to 2024, and the budget of the first edition was PLN 100 million [79]. Within its framework, it is possible to obtain funding for the construction of a rain garden on a property [31].

Discounts and rebates are other solutions that encourage owners and managers to build rain gardens and, thus, facilitate their introduction to cities. For example, the Water-Wise Rainscape Rebate program by Austin Water, Austin, TX, US, a water service provider that targets residential and school areas to help install rainwater retention solutions on properties. For each “changed” square foot of land, a rebate of USD 0.30 is obtained (after meeting the conditions specified in the program) [30]. Among other programs, it is worth mentioning the creation of rain gardens by the Management Board of Municipal Buildings in Kraków. As part of the project, activities are carried out to manage rainwater in municipal real estate. Within its framework, rain gardens up to areas of 20 m<sup>2</sup> can be created, connected with a rainwater reservoir supplying this green area [80,81].

The recipients of this group of facilities are mainly owners of private real estate and residents of blocks of flats.

### 5.5. Multi-Criteria Building Assessment Systems

Among the measures taken to accelerate the introduction of these types of gardens to cities, there are also multi-criteria building assessment systems, such as BREEAM or LEED, in which “points” can be obtained by investors also for the construction of rain gardens. In the case of the LEED Building Design and Construction (BD + C) category and various schemes under this category (e.g., new construction), it is possible to earn points for the construction of a rain garden, e.g., in the credit category, sustainable sites, under the rainwater management credit (up to three points) [41]. Under the BREEAM scheme—a scheme for new construction—points for the construction of a rain garden can be obtained, for example, under such environmental sections as: land use and ecology



(enhancing site ecology) or pollution (the issue assessed is surface water runoff) [42]. These types of facilities are intended for investors.

Figure 3 summarizes the currently available amenities used to introduce rain gardens into the urban fabric, when building awareness in a society and in the decision-making process, as well as the stages involving the design, implementation, and maintenance of these LID practices.



**Figure 3.** The classification of facilitations of the rain garden application in a city, depending on the implementation stage of the solution.

## 6. Summary and Conclusions

Rain gardens are becoming more popular, particularly in the face of climate change (and due to the need for cities to adapt to the impacts of climate change). These gardens are important solutions in green infrastructure, mainly due to the ease of their implementation and relatively low costs (with the possibility of reducing costs to a minimum, assuming the own user's contributions).

In this article, we separated the issues pertaining to rain gardens, into benefits resulting from their use, inconveniences during implementation, and maintenance of such solutions in urban tissue; we added a category (called facilitations) concerning the introduction and maintenance of this type of LID practice. For easier comparisons, the benefits, inconveniences, and facilities, in terms of introducing rain gardens into the urban fabric, are summarized in Table 1.

In the discussion on the advantages—the benefits for the environment (water protection, groundwater recharge) were taken into account, as well as profits for residents and potential economic benefits.

Among the disadvantages discussed—limitations in the application and problems that may arise during operation, resulting mainly from errors in the design or realization, and the scope of work related to the maintenance of such solutions—were taken into account. The issues of costs, space requirements, and social aspects were also considered.

The discussion presented drawbacks that occur during the implementation and maintenance of rain gardens, which can be divided into (1) those for which amenities can be

found, developed, or prepared, and (2) those for which there are no effective solutions (yet). In the future, it may also be possible to develop facilities for all inconveniences surrounding rain gardens.

**Table 1.** List of benefits, inconveniences, and facilitations in the implementation of rain gardens in the city, own study based on the literature [8–81].

| Benefits   | Drawbacks   | Facilities  |
|--|---|---|
| <ul style="list-style-type: none"> <li>• Participation in rainwater management (reduction of peak flows in the sewage system, reduction of the volume of rainwater runoff from the catchment area, reduction of the probability of rainwater/combined sewage system overload, reduction of the risk of property flooding if properly located)</li> <li>• Water protection (removal of pollutants from rainwater, groundwater recharge)</li> <li>• Other benefits for the natural environment (they provide a habitat for the local ecosystem, may have a positive effect on biodiversity)</li> <li>• Social aspect—social integration</li> <li>• Health aspects</li> <li>• Temporary storage of water; higher evaporation and improvement of microclimate</li> <li>• Economic benefits (saving water for irrigation of green areas, discounts or reduction of fees related to rainwater management)</li> <li>• Reducing the urban heat island effect</li> <li>• Impact on air quality</li> <li>• Improvement of the aesthetics of the landscape thanks to the aesthetic value</li> <li>• Relatively short time from decision to implementation (due to the ease of design and implementation)</li> <li>• Points in multi-criteria building assessment systems</li> <li>• Mitigating the effects of climate change</li> </ul> | <ul style="list-style-type: none"> <li>• Possible problems in case of errors in the design and construction</li> <li>• Possible problems in case of improper operation</li> <li>• Surface requirement (depending on the type of soil, up to more than half of the draining area)</li> <li>• In some cases, it is not possible to implement this type of LID practice (e.g., high groundwater level, high slope)</li> <li>• Restrictions when choosing a location (e.g., the required distance from the foundations)</li> <li>• Costs</li> <li>• Need for maintenance and management during operations</li> <li>• Social aspects: possible lack of community support, neighborhood conflicts, community fears</li> <li>• Reluctance of investors to incur additional investment costs</li> </ul> | <ul style="list-style-type: none"> <li>• Computer programs, including for modeling green infrastructure, costs/outflow calculators, mobile application</li> <li>• Websites and webpages</li> <li>• Manuals, guides, instructions, fact sheets (including those concerning proper communication with communities)</li> <li>• Videos (training, instructional), webinars</li> <li>• Online courses</li> <li>• Workshops and training</li> <li>• Co-financing programs, rebates</li> <li>• The possibility of obtaining points as part of multi-criteria building assessment systems (BREEAM, LEED)</li> </ul> |

When analyzing the possibilities of using various solutions in the field of blue–green infrastructure or LID practices, it is important to consider the various dimensions of the

benefits and disadvantages of these solutions. It is important to apply a complex approach to this type of analysis, and not focus only on the main purpose of the solution. Moreover, in the perspective of works on the development of rain gardens, emphasis should be placed on the integration of environmental, technical, and sociological aspects. For this reason, it is important to create interdisciplinary teams, including gardeners, landscape architects, sanitary and environmental engineers, doctors, sociologists, and biologists. This list likely does not exhaust all needs. Only fully adapted solutions could harmoniously be introduced into the fabric of a city, without raising protest, serving people and their environments.

There is great potential in rain gardens; due to their decisive advantages over such popular green roofs, in terms of the possibility of introducing them to cities (especially their central parts), they are “future-proof” solutions for highly urbanized areas. Decisions made by decision-makers regarding the selection of appropriate solutions in the field of blue and green infrastructure should be preceded by a comprehensive analysis of the issue (as was one of the goals of this work).

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