


## Article

# Afforestation of Urban Brownfields as a Nature-Based Solution. Experiences from a Project in Leipzig (Germany)

Dieter Rink <sup>1,\*</sup>  and Catrin Schmidt <sup>2</sup>

<sup>1</sup> Department of Urban and Environmental Sociology, Helmholtz Centre for Environmental Research-UFZ, 04318 Leipzig, Germany

<sup>2</sup> Institute of Landscape Architecture, University of Dresden (TU Dresden), 01062 Dresden, Germany; catrin.schmidt@tu-dresden.de

\* Correspondence: dieter.rink@ufz.de

**Abstract:** In Leipzig, despite strong growth, reurbanization and re-densification, in the last decade it has still been possible for the city to green brownfields with a new type of green space: urban forests. The background to this was of course the city's decades of shrinkage and the emergence of numerous brownfields. The city of Leipzig started urban redevelopment in 2001 and pursued the strategy "more green, less density" in its planning. This included the creation of traditional and new green spaces as well as temporary uses. New green space concepts were also experimented with, including pocket forests and urban forests on larger, inner-city brownfields. This pursued several objectives: the forest was meant to contribute to improving the urban climatic and air-hygienic situation, to enhance the value of adjacent areas, create new recreational opportunities and contribute to increasing biodiversity. Another aspect is also the financing, for instance, the afforestation of brownfields is the cheapest way to create greenery. As a result of almost ten years of interdisciplinary monitoring of the project, it can now be stated that urban forests fulfil the objectives and are accepted and used by the population. Urban forests do not constitute an independent or new type of nature-based solutions they create new ecosystems from existing abandoned, brownfields, or neglected area.

**Keywords:** greening; brownfields; urban forests; green infrastructure; nature-based solution



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## 1. Introduction

In the last decade, reurbanization and growth have been the dominant developments in German and many major European cities. As the cities have grown and developed, brownfield and open spaces have often been used for new developments, especially residential buildings. This has led to redensification, and in some cases even to the conversion of green spaces. This trend runs counter to demands and efforts to preserve or even increase green and open spaces. These efforts are driven by the need for climate protection and adaptation as well as by the sustainability goals that many cities are pursuing. Last but not least, open and green spaces are seen as an indispensable part of urban quality of life. In this way, "it has become necessary to strengthen the ecosystem services in the city and implement new urban nature-based solution initiatives with the goals of improving the quality of the environment and creating a greener, more liveable city" [1] (p. 4). According to the European Commission, nature-based solutions are "actions inspired by, supported by or copied from nature; both using and enhancing existing solutions to challenges, as well as exploring more novel solutions, for example, mimicking how non-human organisms and communities cope with environmental extremes . . . Nature-Based Solutions aim to help societies address a variety of environmental, social and economic challenges in sustainable ways," [2] (p. 24) [3,4]. Forests represent a specific nature-based solution: they are considered to be of particular importance for climate protection and for adapting to climate change, because they store greenhouse gases and have a positive influence on the urban microclimate. In addition, urban forests increase the quality of life by providing spaces for

local recreation and they contribute to the enhancement of neighbourhoods. This paper will examine the extent to which these goals can actually be achieved through afforestation in the inner city. It is based on an example from the city of Leipzig (Germany), where a model project was carried out in the 2010s with the aim of creating new urban forests. Despite reurbanization, growth and densification, the city of Leipzig succeeded in creating three new urban forests. The afforestation initiative is noteworthy because it took place on inner-city brownfield sites that resulted from urban redevelopment or revitalization. The context of origin and the classification of these brownfields must be taken into account, as they represent the framework conditions for the newly created forests.

Otherwise, urban forests are of course not a new phenomenon; they have been around for a very long time and have been the subject of an intensified discussion in the literature since the 2000s. In the English-speaking world, the terms ‘urban forest’ or ‘urban forestry’ have even existed since the 1960s; an overview of the development of the term ‘urban forest’ in the North American context can be found in Johnston [5,6]. The discourse on urban forests was conducted primarily in the Anglo-Saxon-speaking world until the mid-1990s. From the end of the 1990s onwards, there were various projects that initially dealt with questions of urban forestry, but that also included sustainability aspects—in the sense of a social-participatory perspective. These include, for example: “EUFORIC—European Forestry Research and Information Centre”, “Neighbourhood Woods”, “COST Action E12 Urban Forest and Trees”, or “Urban Wood for People—Demonstration of Ways to Increase Recreationable benefits from Urban Woodlands” [7]. In the last decade, the Food and Agriculture Organization of the United Nations (FAO) has also focused intensively on urban forests; they have presented a collection of international examples [8] and published a special issue with analysis [9].

There are no clear definitions of urban forests, because even the term ‘forest’ depends on specific and individual types of forest [10] (pp. 50–52). The FAO has defined urban and peri-urban forests as “networks or systems comprising all woodlands, groups of trees, and individual trees located in and around urban areas” [11] (p. 2). A similar concept can be found in Kowarik, who classifies forests in terms of their spatial location and their relationship to settlement areas. In addition to peri-urban and non-urban forests [12] (p. 5), there are urban forests, which he describes as “completely surrounded by developed areas” or as “forest island in the city” [12] (p. 4). Here we follow the definition on which the project was based and where the focus was on planning. According to this definition, “urban forests ( . . . ) are forest areas in inner-city, often densely built-up areas. They represent a separate category of open space with special significance for urban redevelopment, for urban ecology—especially for the adaptation of cities to climate change—and for recreation” [10] (p. 32). Urban forests are usually found on anthropogenically deformed sites of residential, railway, industrial and commercial brownfields. Moreover, these forests can be very small, although it must be assumed that a minimum area of 0.3 hectares or a minimum diameter of approx. 50 m is required in order to ensure ecological stability [10] (p. 33). Furthermore, urban forests should have a minimum level of equipment and accessibility in order to be used and accepted by the population [10] (p. 33). This paper specifically deals with the urban forests that are created through afforestation on inner-city brownfield sites. The paper refers to three cases to show the diversity and variety of new urban forests. The aim of the scientific research on the new urban forests in Leipzig was to find out to what extent different ecological and social goals could be implemented here and to what extent they can be recommended as a nature-based solution for urban brownfields.

The aim of the interdisciplinary research was to investigate whether the new urban forests fulfil the ambitions associated with them and to assess the success of three urban forests implemented as nature-based solution in the shrunken city of Leipzig. Improvements in urban microclimate, environmental quality, added value to neighboring areas, recreational opportunities, and biodiversity has been assessed.

## 2. Background: Urban Brownfields and Afforestation as an Option for Urban Restructuring

Although urban brownfields are a global phenomenon [13,14], they are portrayed very differently according to world region and city. Brownfields are “sites that have been affected by the former uses of the site and the surrounding land; are derelict and underused; may have real or perceived contamination problems; are mainly in developed urban areas; and require intervention to bring them back to beneficial use” [13] (p. 274). In shrinking cities, the brownfield problem is usually more obvious, caused by the process of deindustrialization, suburbanization as well as population decrease. Known examples for this are Detroit with its ‘doughnut effect’, or old-industrialized regions in Europe, such as the north-west of England, the Ruhr area in Germany or the Upper Silesian industrial area in Poland. In eastern Germany, the brownfield problem has become particularly prevalent as a result of the concurrency, or the combined effect of massive deindustrialization, suburbanization, and demilitarization, the structural change in the transport sector as well as a large decrease in population [15]. This has led to the creation of a huge number of brownfields in a series of affected cities. This problem has developed to such an extent that it has led to a breakup of urban structures. In planning and urbanistic discourses this is also characterised and discussed using the term ‘perforation’ [16]. Inner-city (older) areas are particularly affected by this, as they are distinguished by an increasing number of industrial, commercial, and residential brownfields and are also characterised by decay and vacancies. Due to the low or non-existent demand for the sites, there is a general uncertainty in such quarters about their further development. It is unclear whether and, if so, when the brownfields will be needed again; many are in an unsafe state and have succumbed to natural succession, which, in the eyes of the residents, reinforces the perception of their neighbourhoods as shrinking or in decline [17,18].

Against the background of this development, the most obvious question is: how can one generally deal with this problem and how does one want to deal with it? Under these conditions, what might be sensible interim uses or subsequent uses? How can one deal with the unplanned continuing spread of brownfields in design and planning? In view of scarce resources and capacity, particularly in shrinking cities, solutions are required that help enhance the residential quarters, but are also inexpensive in their design and maintenance. They must also be flexible and may not completely exclude other future uses, for instance in the form of construction.

Overall, brownfields posed a new urban problem for which there were neither resources nor instruments. Together with other issues, the topic of brownfields reached the agenda of urban redevelopment in eastern Germany in 2000 and became a topic of intensive research, development and planning work. As a result, some cities in eastern Germany have developed or introduced new strategies, instruments and tools for dealing with brownfields, such as different forms of interim use or renaturation [19] (pp. 383–385) [20]. One form that has been developed is the so-called ‘urban forests’—this refers to the afforestation of urban brownfields. Normally, this instrument has been used alone and almost always on the urban periphery, for instance to close up gaps formed by the demolition of houses, to complete greenways or to connect the sites to the surrounding countryside. Forests are considered to have a high potential for the reuse of urban brownfields [21] (p. 201). This use category is regarded as multifaceted in terms of function, design and law, which makes it particularly suited to react to uncertain conditions. As a new category of open space, they would be a space-defining element in urban redevelopment and, in contrast to most brownfields, they would not represent a foreign element, but rather “visually and functionally interlock the perforated urban structures” [10] (p. 119). Accordingly, urban forests are said to have a great effect on urban design and urban structure [21] (p. 201). In particular, the use of different forest structure types allows a targeted influence on urban structure and townscapes [10] (p. 119). According to the German Forest Act, any area permanently planted with woody plants is to be regarded as forest land—irrespective of the actual designation of the land and the respective ownership structure or form of management [10]

(p. 8). For the establishment of forest on brownfields or former residential land, this means that it is neither dependent on planning decisions nor on ownership relationships; land readjustment is also unnecessary [10] (p. 119).

In addition, forest allows for a wide—and far from exhausted—range of designs and uses and can thus be adapted very flexibly to local conditions. This refers to its size and shape, its development as a commercial forest, recreational forest or near-natural forest stand. In addition, the existing vegetation—for example on brownfields—can be included in the planting and design and supplemented depending on the objective. However, forest can also be used to create spatially effective structures—such as road edges and boundaries or connections between previously separate areas. One of the advantages of forests is that they are accessible to the public and have fewer security requirements than, for example, public green spaces. It is also much cheaper to maintain and care for forests than public green spaces; with reference to figures from Berlin, Giseke speaks of one tenth of the costs [21] (p. 202); Burkhardt et al. also refer to the lower investment and management costs and the associated relief effects for the municipal budget [10] (p. 119). They also point out that urban forests would have positive indirect monetary effects, such as the valorisation of neighbouring properties (*ibid.*). Burkhardt et al. also argue that urban forests can combine the advantages of green spaces (usability and acceptance) with those of brownfields (low cost, ecological effectiveness): “Although they can neither replace green spaces nor brownfields without restrictions, they offer a broad spectrum of functions and possible uses at comparatively low costs and high acceptance” (*ibid.*, pp. 119–121). Burkhardt et al. also draw attention to the limits of urban forests: for example, they consider the fact that only a short-term interim use is to be established if a minimum size is not reached (for this they state the size of 0.5 ha) and if “exclusively representative or special design requirements exist for an open space”, as is the case, e.g., with ornamental or market squares (*ibid.*, p. 121). In contrast, disadvantages are not stated, e.g., that there are lingering stigmatisations, that the areas are initially fenced in and can therefore only be used to a limited extent, that the population rejects the action and sees it as a cheap greening option, etc. A few years ago, Kil said that afforestation—next to natural succession—was by far the most cost-effective option for brownfields in shrinking cities, but that in the previous consensus for inner-city open spaces it was still considered out of the question [22] (p. 144). He blames this on traditional images of cultivated urban nature: “Apparently our society, shaped by Western cultural concepts, cannot simply let go of the image of the ‘controlled landscape’” (*ibid.*). In the federal programme “Stadtumbau Ost” (Urban Restructuring East) there are several examples of the reforestation of urban brownfields, for example in Eisenhüttenstadt, Halle, Schwedt and Weißwasser. While afforestation was carried out on the respective peripheries of these cities, the distinguishing feature in Leipzig is that urban forests were created on inner-city brownfield sites.

### 3. Case Study Leipzig: From Shrinkage to Urban Restructuring

The background in Leipzig, the city that will be discussed here, is a long period of shrinkage that increased during the period of post-socialist transformation in the 1990s. As a result of deindustrialization in the 1990s, the abandonment of military sites and structural change in the transport sector after reunification, numerous areas fell into disuse. In 2007, there were just under 2000 brownfields in Leipzig, which together covered about 700 hectares and corresponded to about 2.6% of the settlement area—very high values [23] (p. 19). Although these brownfields are found throughout the whole city, they are concentrated in the former industrial and working-class districts in the east and west of the inner city (*ibid.*). For many, even large areas of up to 20 or even 30 hectares, there was no demand, and no subsequent use was feasible. The city of Leipzig started urban redevelopment in 2001 and pursued the strategy “more green, less density” in its planning [24]. This included the creation of classic and new green spaces as well as interim uses. It also experimented with new green space concepts, such as planting trees on small inner-city urban redevelopment sites in the mid-2000s. On Leipzig’s east side, the ‘light

grove' and the 'dark forest' were created, which, however, provoked criticism and protests. There were complaints about the demolition of valuable Gründerzeit (Wilhelminian-style) houses and the loss of urban qualities. A few years later, the idea arose to create urban forests on larger inner-city brownfield sites.

The Leipzig project: "Urban Forests: Ecological Urban Renewal Through the Creation of Urban Forest Areas on Inner-City Sites Undergoing a Change of Use" is one of the most ambitious renaturation projects. While reforestation in other cities is mainly concentrated on residential brownfields that arose in the course of the deconstruction of peripheral large housing estates, in Leipzig's inner city, brownfields are also being considered for conversion into forest. In addition, the Leipzig project is embedded in a "testing and development project" (E+E project) initiated by the city of Leipzig and the Federal Agency for Nature Conservation (BfN). The BfN's funding programmes pursue various overarching goals. In addition to the integration of nature conservation into urban development, these include the implementation of reliable research results in practice, testing new and improved applications of already tried and tested methods, and processing the experience gained for generally usable recommendations. Since the E+E projects are intended to have a domino effect nationwide, the practical application of the concepts is the focus of the projects. Characteristic for the Leipzig project is the strong heterogeneity of the brownfields, which underlines the model character of the project. The spectrum ranges from residential and commercial brownfields to railway and industrial brownfields, which are located in the inner city but also in peripheral locations and which are partly in municipal and partly in private hands. The wide variety can also be seen in the size of the sites, which range from very large sites (20 ha) to very small sites (<1 ha). In contrast to other urban redevelopment municipalities, the city of Leipzig has the ambition to see renaturation not merely as a reaction to the emergence of brownfields, but to develop differentiated, innovative and transferable solutions. The aim is to develop urban forests as a new land and planning category and to establish them as an instrument for urban redevelopment. However, the task set is by no means trivial; above all, the procurement of land appears to be problematic. Whereas in other municipalities negotiations were held with a few, mostly municipal or semi-municipal landowners, in Leipzig new negotiations have to be held with each landowner, which greatly delays planning and implementation and—if conflicts of interest are too strong—may even prevent them altogether.

The model project pursues several goals: the urban forests are intended to improve the urban microclimate and air quality. They should improve the surrounding neighborhoods, they should create new recreational opportunities for the residents. They should enrich biodiversity in the city by contributing to an increase in species diversity. Furthermore, the aim for planning is that a new category of open space is created that gives urban forests their own status. One aspect is also financing, as afforestation of brownfields is the cheapest form of greening. First, a feasibility study was conducted in 2007–2008, which yielded positive results. This was followed by the testing and development project (E + E project), which was funded by the Federal Agency for Nature Conservation (BfN) and carried out together with the city of Leipzig from 2009 to 2018. It involved the replanting of three urban forests on inner-city brownfield sites.

## 4. Methods and Materials

### 4.1. Methods

In the accompanying scientific research of the project, an interdisciplinary approach was chosen in which natural and social science methods were used. In order to actually be able to make sound statements about the contributions of the new urban forests to urban biodiversity, climate protection, improvement of the microclimate, improvement of neighbourhoods with greenery and local recreation, a longer period was chosen. The scientific monitoring started with the establishment of the first urban forest in 2010, after which repeat studies were carried out until 2018—i.e., over a period of almost ten years.



This was to ensure that robust statements could be made on the questions and issues of interest.

With regard to the public perception and use of the new urban forests, a household survey was conducted by the Helmholtz Centre for Environmental Research—UFZ Leipzig at the beginning in 2010 in the neighbourhoods where the new urban forests were to be established, which were four urban areas. A radius of 500 m was made around each of 4 locations of the planned urban forests, in which the questionnaires were then distributed and collected again according to a fixed key [25]. The focus of this survey, which worked with pictures, was the residents' preferences for the design and use of the new urban forests [25]. In order to record the development of recreational use of the three new forests, counts, observations, and surveys of residents were conducted on each site. This was done after the creation of the forest and for comparison two to three years later. In addition, differences in the recreation profile of urban forests and parks were investigated by counting recreationists in five other, also older forests and comparatively six parks in Leipzig and Dresden by the Technical University Dresden [26]. The impact of urban forests on surrounding urban neighbourhoods was analyzed by on-site surveys of the vacancy rate of apartments in the surrounding area of each of five brownfields, parks, and forests in Leipzig. Similarly, the vacancy rate of stores was also investigated in the vicinity of two brownfield sites, parks and forests in Leipzig [27].

In order to document the development of the vegetation in the three newly established forests, forest botanists from the Technical University Dresden examined vegetation records according to Braun-Blanquet once a year over a total period of ten years on representative permanent observation plots with an area of 100 m<sup>2</sup> or 25 m<sup>2</sup> (subplots). The development of the trees was analyzed in detail on the basis of the development of shoot length, stem diameter as well as the annual shoot lengths on firmly marked specimens. In addition, a comparative study was carried out between parks, urban brownfields and urban forests. In this study, model plots were selected for each district of Leipzig (19 in total), in which a vegetation survey was carried out [28]. In parallel, the change in fauna in the three new forests was recorded by the Nature Conservation Institute of the Leipzig Region e.V. by mapping the avifauna and reptiles in 2009, 2014 and 2017/2018. In addition, a mapping of bats and a comparative study of avifauna were carried out in four reference forests of different ages in Leipzig [29]. Soil profiles and soil samples were investigated by the Chair of Landscape Planning of the Technical University (TU) Dresden on six brownfields in Leipzig and, for comparison, in six forests of different ages according to different soil parameters. At the same time, soil from the three newly established urban forests was analyzed in depth [30]. The influence of urban forests on temperature development was investigated by the Chair of Meteorology of the TU Dresden based on measurements of a specially established climate station (Stadtgärtnereiholz) as well as mobile measurement tours through built-up urban quarters of varying densities and differently aged forests in Leipzig. In addition, the microclimatic conditions for two of the three new forests were simulated using the three-dimensional urban climate model ENVI-met. The impact of urban forests on air quality was assessed by measurements on the one hand and model-based simulations on the other hand. In addition, a simulation on the carbon sink capacity of urban greenery was carried out using the SVAT-CN and HIRVAC climate models [31].

#### 4.2. Materials

The first "Stadtgärtnerei-Holz" area was created in 2010 on the site of the former municipal garden in Anger-Crottendorf, a district in the east of Leipzig. The city-designated garden had ceased operations in 2005, after which it was unclear what would happen to the area. The city, which owned the site, tried to sell it, but failed. Afterwards, new concepts or ideas for use were sought. Due to its size—approx. 3.8 ha—it came to the attention of the project and was selected as a possible reforestation area. To do so, the area had to be cleared at relatively high cost, the greenhouses and permanent buildings were demolished, but the main path was left as a passageway through the site. A number of trees and shrubs

from the previous use have been preserved and incorporated into the new design. This also applies to some concrete elements that now serve as seating. The reforestation was based on the former use and the areas were divided into parcels. The choice of tree species and shrubs was intensively discussed, and a decision was made early on in favour of a variety of species. As with all new forests, the selection of tree species was based primarily on the local conditions (soil, climate, water), but also on the history of the site, the design and forestry conditions. At the same time, different tree species were to be tested. For the tree species, oaks, lime trees, hackberry, rowan and walnut trees were chosen, while hazel, hawthorn, barberry and elderberry were planted as shrubs. Since the *Stadtgärtnerei-Holz* and also the other two new forests were to be managed by forestry, mainly 'forest products' were used. In key space-defining areas, larger trees were planted in exceptional cases. The row spacing was 2 m, the spacing of plants within a row 0.5–0.9 m [32].

The afforested plots were initially fenced off for five years. When the fences were dismantled in 2015, the entire area was handed over to the municipal forestry department and is now the responsibility of the foresters. To reinforce the impression of a forest, three high seats were installed in the area. If you ascend them, you can get a good view of the area and the surroundings. Young people had been using the area illegally and spray-painting the old greenhouses; to give them a run for their money, the wall of an adjacent house was officially graffitied. This could not completely prevent individual acts of vandalism, but overall, the area is in good condition, the trees are now about 4 to 5 m high, and the ambience of a forest is visibly developing (see Figure 1).



**Figure 1.** The urban forest *Stadtgärtnerei-Holz*, ten years after planting.

The second area, the *Schönauer Holz*, was afforested three years later, in 2013, in the large *Grünau* housing estate on the western outskirts of Leipzig. This urban forest is located in the middle of a still densely populated residential area between blocks. One of the city's largest prefabricated slab buildings once stood here, a long eleven-storey building. It was popularly nicknamed the 'Eiger North Wall' by the people of *Grünau* because of its size and height. Due to the severe shrinkage in *Grünau* from almost 90,000 inhabitants at the end of the 1980s to about 45,000 at the beginning of the 2010s, *Grünau* had become the focus of urban redevelopment. The eleven-storey building on *Neue Leipziger Straße* had come into focus early on and was demolished with public funds in 2007. Afterwards, grass was sown, which only partially grew in due to the poor substrate. The area was hardly used by the population, but served as a pathway between the blocks and the nearby

shopping and service facilities. The city bought part of the 5.5 ha area and developed a design concept for the urban forest. Here, the population was involved in the planting and design from the very beginning. During the reforestation, school children participated in a tree planting campaign. Existing elements were incorporated here as well, such as the existing paths and trees or some concrete elements that serve as seating. In addition, high stands were erected again (two), which have become landmarks of the urban forests in the meantime. As far as the tree species are concerned, rowan, wild service tree and European aspen were chosen. This area was also well accepted by the population, although there has been vandalism there as well, such as theft of trees or spraying of the signs. In the meantime, the trees are 2–3 m tall and the fences were removed in 2018, making all areas accessible (see Figure 2).



**Figure 2.** The urban forest Schönauer Holz seven years after planting.

The third site, Bürgerbahnhof Plagwitz, is located to the west on the edge of Leipzig's Wilhelminian development and is the largest site at around 15 ha. Once one of Germany's largest freight stations, it was completely derelict in the early 1990s. After that, there were only illegal interim uses, but at the end of the 2000s the area came to the attention of local residents. In 2009, the Initiative Bürgerbahnhof Plagwitz (IBBP) was founded, which also gave the area its new name. Since 2010, the initiative has organised 'discovery walks' or 'track breakfasts' and developed its own ideas for transforming the brownfield. Since 2015, a major event, the "Westbesuch" district festival, has also taken place at the Plagwitz civic railway station. The concept of the urban forest on the former railway site is consequently quite different from the two urban forests described above. Here, various other uses were integrated into the "Gleis-Grün-Zug Bahnhof Plagwitz" from the outset, and nature conservation concerns had to be taken into account. The groups and initiatives were involved in the planning and design from the beginning; a series of workshops and participation opportunities served this purpose. It is noteworthy that the existing succession forest in the southern part of the area—approx. 4.3 ha—was included in the overall design and continues to be left alone (see Figure 3). Here there are also sites that are valuable for nature conservation, such as special species living in very dry conditions. Only after long and complicated land negotiations was the city able to buy the area from the German railroad company, Deutsche Bahn. The entire area was gradually developed; in 2013, a bouldering rock and an air swing were inaugurated at the so-called 'Nordkopf', in 2016, a playground and scouts followed, and a year later, the first trees were



planted in the fruit grove and orchard, which are tended by neighbourhood residents. An urban forest with oak trees has been created on approximately 1.5 ha and a sport field was opened in 2019. The City of Leipzig, the Free State of Saxony and the European Union also participated in the financing of the various designs and projects at the Bürgerbahnhof Plagwitz. In contrast to the first two examples, the Bürgerbahnhof Plagwitz is used much more intensively; numerous groups, initiatives and associations as well as citizens from the surrounding neighbourhood have ‘appropriated’ it. There has been no major vandalism here so far.



**Figure 3.** The urban forest “Karl-Heine-Holz”—natural succession.

All three model areas represent different types of brownfield land (horticultural fallow, residential and railroad brownfields) with different site conditions. At the same time, different types of forest were created (multi-layered dense or rather light, high or rather lower) and different strategies of forest planting were pursued (reforestation, succession). The planning recommendations derived from this were summarized in a ‘toolbox’ for all interested parties. This is publicly available on the homepage [32]. The location of the three new urban forests in the city area can be seen on the following map (see Figure 4).



**Figure 4.** Urban forests in the Leipzig urban area.

## 5. Results

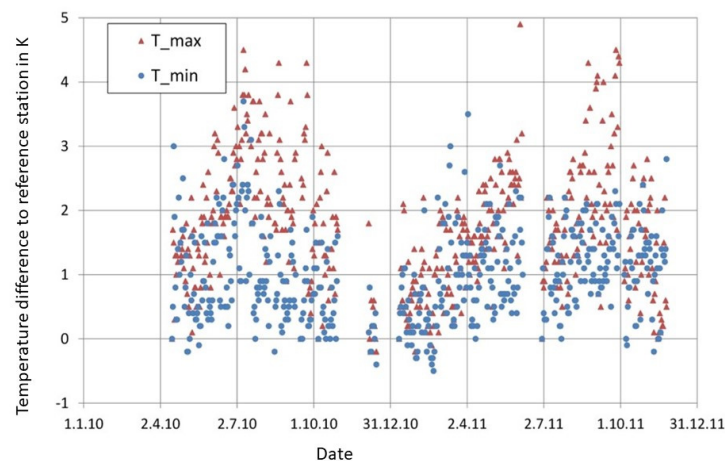
### 5.1. Acceptance of the New Forests by the Population

The sociological survey conducted in 2010 showed that the design of brownfield sites as urban forests is generally accepted and positively perceived by the population [25]. From the population's point of view, urban forests enhance brownfield sites, make them usable and enrich the cityscape. Forests are generally highly valued by the urban population, but urban forests are not necessarily perceived as forest areas in the first few years after they are planted, and sometimes they cause confusion due to their appearance. Especially in the first years of planting, the area is still associated with a brownfield or 'wilderness' and only secondarily with a usable green space or a forest [25]. As growth progresses, acceptance of the area and its planting increases, but a sense of forest only emerges over time. This is also attached to the relatively small size of the area. Furthermore, the limited usability of urban forests makes acceptance by the population more difficult. By means of a picture survey, the acceptance of succession and afforestation to urban forests was measured in the quantitative survey. A Likert scale was used, from 1 = "like it not at all" to 4 = "like it very much". These two variants were explained to the respondents at the beginning as alternatives and then compared pictorially. The different succession stages are rated significantly worse than afforestation and achieve values between 1.19 (early succession stage) and 2.58 (advanced succession stage) on the four-point scale [25]. Afforestation, on the other hand, reaches values between 2.45 (early afforestation stage) and 3.46 (advanced forest stage) [25]. The fencing off of the afforestation areas limits accessibility and there is a lack of direct experience. The residents expect something similar from an urban forest as they do from classic green spaces, most likely a park-like design and equipment. It has to be said that the afforestation of brownfields is only a second-best solution for the population. The participants in the 2010 household survey wanted paved paths, rubbish bins, benches and seating as well as lighting (ibid.). With regard to use, surveys carried out in 2014 and 2017 revealed that the areas are primarily used by pedestrians and cyclists as passageways [33,34]. The duration of use is accordingly short, usually less than 15 min. Other uses include jogging or walking the dog; families and children

in particular use the urban forests more intensively or for longer periods. The uses thus correspond to the character of the areas, because an increased number of visitors or typical park activities such as picnics, barbecues or ball games would be less appropriate for the setting of urban forests. The user groups are mainly residents or people from the immediate vicinity [34]. More intensive forms of use can be found where there are other offers, such as at the Bürgerbahnhof Plagwitz, where there is urban gardening, a playground and even gastronomy.

### 5.2. Ecological Benefits of Urban Forests

One positive ecological effect of urban forests is the reduction of heat effects. The measurements carried out in Leipzig as part of the research project prove, for example, that the shading effects of old trees in summer can lead to a reduction in the maximum daily global radiation of up to 1/14 of the reference value. This means that the daytime maxima of the air temperature under the trees in summer can be more than five Kelvin degrees lower. This was proven on the one hand by mobile measurement tours through Leipzig, and on the other hand by two measurement stations. One of them was located under old trees, while the reference station is unshaded (see Figure 5).

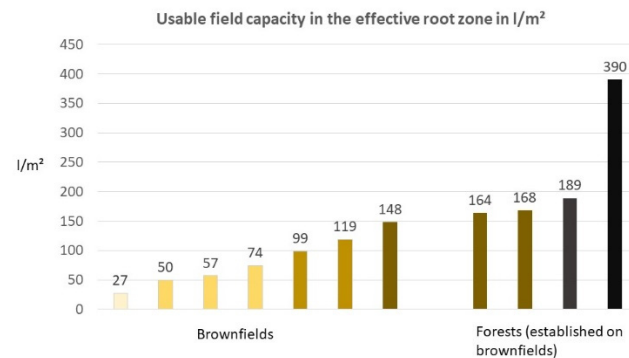


**Figure 5.** Temperature difference between a measuring station under old trees (KLIMA) and the reference station at the University of Leipzig [27].

In one temperature measurement run, for example, it was about 5–6 K cooler in the Stötteritz forest than in the city center [27]. Depending on the size and location of the area, the cooling effects can extend up to 400 m [27] into the surrounding built-up urban area. As a rule, the larger the forest, the farther its effect extends. Urban forests can thus reduce heat loads even better than parks dominated by open land during the day. In turn, parks dominated by open land contribute to cooling down at night to a greater extent, so that it is a mosaic of both types of green spaces in cities that matters.

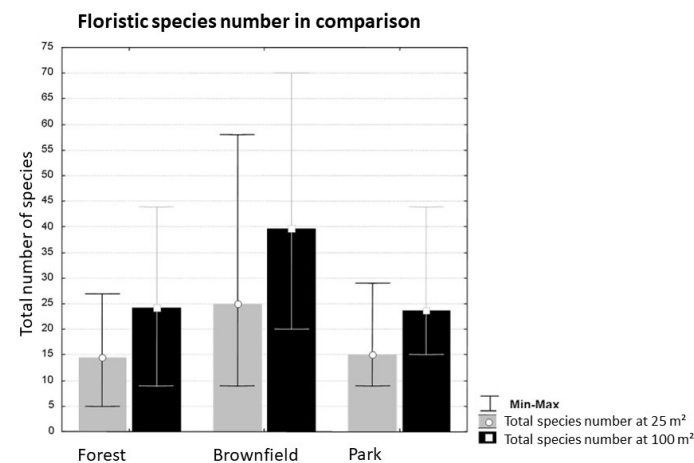
Climate change also causes more heavy rainfall events in certain regions, which can lead to problematic scenarios depending on the degree of sealing. Therefore, field studies were conducted on unwooded brownfield sites and reference forests of different ages. Throughout the study, the investigated brownfields could only retain little rainwater [30]. The rainwater tends to run off the surface because the land is mostly composed of typical urban soils with technogenic admixtures of building rubble. The usable field capacity in relation to the effective rooting depth was only low to very low on brownfields without forest, and their water retention capacity was estimated to be low to medium [30]. The comparative studies in reference forests of different ages (10 to one hundred and fifty years) show that the forest vegetation causes clearly visible positive changes in the soil after just ten to twenty years—namely, increased porosity, aeration, water capacity and rooting depth of the soil as well as improved availability of nutrients. The smallest determined water storage capacity of the investigated forests corresponded to the highest levels of the

brownfield areas (see Figure 6). Therefore, the planting of urban forests on brownfields does indeed tend to help to counteract flood risks.



**Figure 6.** Investigations of the usable field capacity in the effective root depth of fallow land compared to forests [30].

One additional comparative study of different reference forests (according to age and location) with parks dominated by open land and brownfield sites was carried out [32]. The study's results show that brownfields have the highest species diversity in absolute terms, while there were no significant differences between urban forests and parks (see Figure 7). The high species richness of brownfields can be explained by the high variability of site conditions and habitat structures. Forests are the more species-rich, the more diverse their site mosaic is. A study in four reference forests also shows that both the number of breeding bird pairs and the number of breeding bird species tend to increase with the increasing age of the forest [31].



**Figure 7.** Comparative investigation of forest, brownfields and parks according to the total number of species [28].

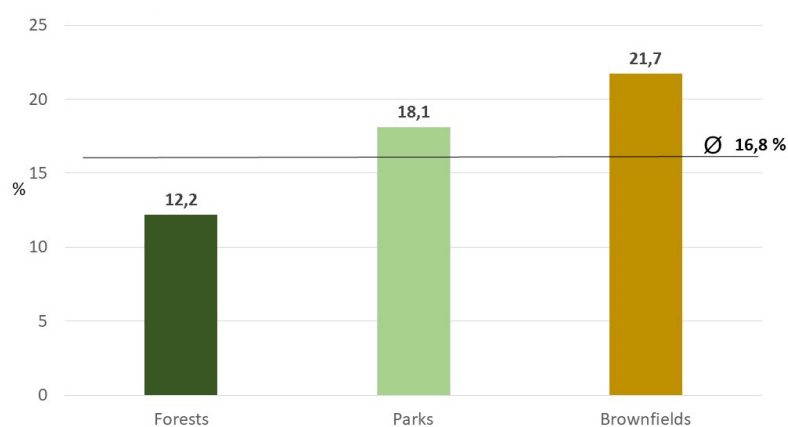
The establishment of urban forests on brownfields usually requires soil improvement. This is because the soils of brownfields tend to be dry and often have a high skeletal content. In formerly sealed areas, an application of topsoil of at least 30 cm is recommended after unsealing [32]. Although topsoil was applied to the unsealed sites before afforestation, the required 30 cm was not achieved throughout, which later led to problems with tree growth. Underground infrastructures were not a problem; with the demolition of the aboveground structures, all underground infrastructures were also removed. The afforestation sites did not show any problematic contamination, as systematic soil tests before planting had shown. Brownfields with contamination must of course be treated before planting trees. The tree species that are planted must be very robust and adapted to climate change. On the other hand, they must also fulfil a variety of aesthetic qualities. Thus, an urban forest



must take the surrounding urban structure into account [32]. Urban forests should reflect and respond to the type and height of the surrounding buildings or the facade structures. Their creation and maintenance, however, at 2.0–2.7 euros/m<sup>2</sup>, is considerably less costly than that of parks [32]. However, at the same time, this means that they are not usually irrigated in the initial phase. Instead of larger trees, small ‘forest products’ are planted. Accordingly, it takes time before a full forest is created.

### 5.3. Effects of Urban Forests on Neighbourhoods

The afforestation of urban brownfields can have a positive impact on the attractiveness of a neighbourhood for its residents. This is also reflected in a mapping of the vacancy rate of apartments in 2013, which examined the apartment vacancy rate in the surrounding area of five forests compared to five brownfields and five parks (a total of 36,297 apartments). The apartment vacancy rate in the surrounding area of the brownfields studied was the highest at 21.7%, significantly higher than in the vicinity of the parks (18.1%) and forests at 12.2% [35]. Overall, the apartment vacancy rate was lowest in the urban neighbourhoods considered around forests (see Figure 8).



**Figure 8.** Comparative investigation of forest, brownfields and parks according to apartment vacancy rate in the surrounding area in percent [35].

The effect is even clearer if we focus on the visual range of open spaces. At about 10%, apartment vacancy was lowest within the visual range of urban forests, and highest at nearly 25% within the visual range around brownfields [35]. While the vacancy rate in the visual range of forests was also about 3% lower than outside the visual range, the exact opposite effect was observed for brownfields. Here, the apartment vacancy rate within the visual range actually increased by approx. 4% as compared to the areas outside the visual range. The visual effect of forests and parks is evidently positive compared to that of brownfields. This becomes clear at the same time when compared to the average of the city quarter. In four of the five forests surveyed, the apartment vacancy rate was lower than the average for the urban neighbourhood. In contrast, apartment vacancy rates in the surrounding area of four of the five brownfields were higher than the average for the urban neighbourhood in which they were located [35].

The brownfields that were afforested in the project also showed positive effects. For example, the vacancy rate of apartments around the site Bürgerbahnhof Plagwitz decreased from 21.6% in 2013 to 7.8% in 2018. However, the reason for this was not only the afforestation, but also Leipzig’s overall positive population development [35].

In addition, the level of leasing of stores in the vicinity of two forests was compared with that in the vicinity of two brownfields and two parks (701 stores in total, mappings in 2010 and 2016). This shows a similar trend to that of apartments. For example, store vacancy was significantly higher in the surrounding area of brownfields (24.8%) than in the surrounding area of parks (20.1%) or forests (13.3%). However, the correlation between store vacancy and surrounding open space is not as close as for apartments. Overall,

though, it has been confirmed in Leipzig that the development of green spaces promotes positive urban development [35].

## 6. Discussion

The concept of urban forests originates from the phase of reurbanization and urban redevelopment in the 2000s [10]. At that time, the effects of shrinkage were still clearly visible in Leipzig and sensible interim and subsequent uses were being considered for a large number of inner-city brownfield sites. At that time, it was assumed that there would be no demand or building use for them in the foreseeable future. However, practically as soon as the ‘urban forests’ project began in the early 2010s, the city of Leipzig entered a phase of dynamic growth that lasted until the start of the COVID-19 pandemic. This manifested itself in relatively high population growth rates (2–3% per year), increased demand for and use of land, and redensification. Even a few years ago, it had to be stated that some of the areas that had been shortlisted for an urban forest are now already planned and partly even built on. Thus—as it appears now—there are hardly any possibilities for the realization of further urban forests in Leipzig at present or in the near future. This clearly shows the limitations of the concept of urban forests in (re)growing cities, and thus the limits of nature-based solutions.

Leipzig is now pursuing the concept of ‘double internal development’ under growth conditions, which includes the establishment and improvement of green spaces, as a growing city also requires (additional) open spaces. Ecological, climatic and recreational effects should be weighed against uses for housing, commerce and social infrastructure [36]. Urban forest can, therefore, definitely be an option for growing cities as well, in terms of sustainable urban development, especially for adaptation to climate change. Thus, so far, urban forests have met with a positive response in Germany, with numerous cities learning about this new green space concept during the course of the project and at the final conference in autumn 2018. It now remains to be seen whether the urban forests will be imitated in other German cities, as was the intention of the project from the beginning.

As a new form of using open space, the urban forest is not comparable with conventional green spaces or existing forests. Its specific usability, its setting, must first be gradually adopted by the population. Planning and administration therefore need ‘staying power’, as the forest qualities and thus the use only develop over time. However, urban forests contribute to the enhancement of the respective residential environment and to the valorisation of the areas immediately after their creation. They have an enriching effect on the open space supply, and they can compensate for deficits in the respective neighbourhoods. Urban forests as defined here represent a new category of open space within the framework of sustainable urban development. The forest characteristics of urban forests develop only gradually and are only slightly pronounced, especially in the initial years after their establishment. The creation of urban forest should, therefore, mean a long-term and permanent use of the area and be in line with long-term urban development strategies.

The Leipzig urban forest project is a pioneering project. Thus, so far, no other studies have been conducted on other urban forests established on brownfields. As far as is known, urban forests in other German cities such as Eisenhüttenstadt, Halle, Schwedt and Weißwasser experience a similar acceptance as those in Leipzig. Internationally, the tree farms that have been established on brownfields in Detroit should also be mentioned here. They enjoy an extraordinarily high level of acceptance and are seen as a way of upgrading deprived neighborhoods: “The value of neighbourhood homes is increasing” (<http://www.hantzfarmsdetroit.com/>; accessed on 24 August 2021).

Extensive recommendations for the establishment of new urban forests were developed from the experiences in Leipzig [32]. For example, a toolbox was developed that is freely available to all interested parties via the homepage <http://urbane-waelder.de/> (accessed on 24 August 2021). It contains, for example, a search filter for tree species selection, with which one can obtain a selection of suitable tree species and a wealth of information about them according to certain site parameters (<https://baumartenauswahl>.

[urbane-waelder.de/](http://urbane-waelder.de/); accessed on 24 August 2021). At the same time, there is a practice-oriented and extensively illustrated handout for planning and designing urban forests ([http://urbane-waelder.de/Bilder/Toolbox\\_B.pdf](http://urbane-waelder.de/Bilder/Toolbox_B.pdf); accessed on 24 August 2021).

The accompanying research within the project could not sufficiently answer or clarify all questions. The studies took place before the urban forests were established or in the first years after afforestation. It can be assumed that the acceptance and use of the forests will increase as they grow and that a sense of being in the forest will develop among visitors over time. In order to investigate this, further surveys and research are necessary, which should take place in the next few years. Further questions could be: How is the specific setting of the urban forest accepted by the population? At what point or under what conditions does a sense of being in the forest develop in the population? Which uses have become firmly established and what differences can be observed over time? How is biodiversity developing in the three forest areas? What effects do the urban forests have on the surrounding neighbourhoods in the long run? From this, further insights can be gained for future urban forests and recommendations for action can be formulated. It would also make sense to include other existing urban forests in Germany and Europe in such studies. Valuable insights could be gained from this, and impulses given for the dissemination of this new urban forest type.

Dushkova and Haase have already analysed several NBS using Leipzig as a case study and have shown their different ecosystem services [1] (p. 20). The question is whether the new urban forests in Leipzig represent an independent NBS type or whether they can be assigned to one of the NBS types elaborated by Dushkova and Haase. In our opinion, the urban forests do not constitute an independent or new type of NBS. Rather, they can be assigned to Type 3: “NBSs that involve creating new ecosystems from existing abandoned, brownfields, or neglected area” [1] (p. 20). The concept of nature-based solutions (NBS) “has been developed in order to operationalize an ecosystem services approach within spatial planning policies and practices, to fully integrate the ecological dimension, and, at the same time, to address current societal challenges” [1]. As shown in this paper, the new urban forests fulfil these requirements in a particular way and function as nature-based solutions.

## 7. Conclusions

It can be stated that urban forests are fundamentally suitable and recommended as a new form of revitalizing brownfield sites. Urban forests are obviously a suitable greening concept for shrinking or shrunken cities. Thus, they can be regarded as an instrument or new open space category of urban redevelopment. They are an NBS with which new ecosystems are created on urban brownfields that fulfil a range of ecosystem services. They have several positive ecological effects, for example on the microclimate and biodiversity. They have a positive impact on the surrounding neighbourhoods, for example on the level of housing vacancy.

In the Leipzig model project, urban forests are considered as a separate, new open space category with specific tasks and services. Urban forests are accepted as a second-best solution and are usually used extensively. The model project in Leipzig can be deemed successful in this respect; it was even possible to plant new urban forests on inner-city brownfield sites despite reurbanization, redensification and (re)growth. However, the limitations are also evident here, as no more suitable areas are available for further urban forests in the present or in the future. In Germany, forests enjoy special legal protection, but urban forests should nevertheless be established as an independent planning category in order to firmly anchor them in green concepts, master plans, climate protection and sustainability concepts. In general, it is important to examine what role the urban forest can play as a nature-based solution in (re)growing cities and in the context of redensification.

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