Urban Tree Placement Analysis: A GIS-Based Approach for Identifying Suitable Planting Locations in Munich

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Abstract: Trees provide various ecosystem services to humans. Therefore, increasing their number in urban areas is necessary. Identifying suitable tree planting locations is essential for cities' resource allocation. However, city-wide information, such as underground pipes, is hardly available. In this paper, we introduce a GIS-based method to identify potential tree planting locations within Munich, utilizing aboveground data. Our methodology combines imperviousness-levels with existing tree data from remote observations. This enables us to investigate tree distribution across different imperviousness levels, identifying areas unsuitable for tree planting. This approach is applied to several land use typologies, thereby identifying suitable planting distances from buildings. We perform a distance analysis for existing trees to identify the nearest neighboring tree for each individual tree. By analyzing the distribution and counts of tree-to-tree distances, a suitable distance between two trees is determined from real-world data. Our case study in Munich exemplifies the methodology. The key findings are that locations with up to 81 % imperviousness can sustain a significant probability for tree planting. Suitable planting distances vary by land use typology. The common spacing between tree pairs is 2.97 meters. The results offer insights into urban areas with a high potential for additional trees, based on above-ground data.

Keywords: Tree Locations, GIS Analysis, Urban Green Infrastructure, Empirical Tree Placement

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1 Introduction

Urban trees are an important element of sustainable and resilient cities [1], [2]. However, planting areas are often limited due to restricted urban land resources, making it essential to identify suitable locations. This process is challenging due to the lack of underground infrastructure data as different institutions manage various underground utilities in cities, leading to fragmented and inconsistent information.

Additionally, street tree planting is complex and difficult to reconfigure, as several interactive constraints must be considered in the decision-making process. To address these issues, we propose a GIS-based method using available above-ground data, including existing tree locations, land use typologies, imperviousness levels, and existing building locations. This approach enables the assessment of urban areas for suitability concerning tree planting. The objective of this study is to present a data-driven methodology that facilitates the increase of urban greenery and allows the identification of suitable tree planting locations.

2 State of the Art

In urban environments, Geographic Information Systems (GIS) are effective tools for identifying potential tree planting sites. Wu et al. [3] developed a GIS method that uses land cover data to accurately determine these locations in a case study in Los Angeles. Their methodology enhances urban forestry planning by ensuring that new trees do not overlap with existing ones and are suitably distanced from impervious surfaces, thereby maximizing ecosystem services. However, this method demands huge computing power. Kirnbauer et al. [4] developed ArcTrees, which identifies plantable areas and suggests tree placement in urban areas. Their approach requires data on urban infrastructure, such as pipes, hydro lines, and gas lines. Buffers between existing infrastructure and new planting locations need to be defined by the user. The authors applied the approach to a case study in Ontario, Canada, and evaluated the shading from additional trees.

GIS clearly plays an important role in identifying potential planting sites and enables the quantification of increased canopy cover. However, the reliability of such methods heavily depends on the accuracy of the input data [5]. Our study proposes an improvement to the existing methods by combining several empirical rules within the GIS framework, intending to provide more accurate tree planting recommendations for urban tree managers.

3 Methodology

The methodology, adapted from Wu et al. [3], comprises two principal modules: 'Site Identification' and 'Tree Placement', as shown in Figure 1. The 'Site Identification' module identifies the ideal planting area, while the 'Tree Placement' module determines the most suitable locations for trees in those areas. The process starts by deriving planting criteria from the existing aboveground data. Therefore, permeable surfaces, distances between existing trees, and distances between trees and buildings are analyzed. As a result of this step, criteria for different land use typologies are developed to ensure sufficient growing space and conditions for new trees.

Subsequently, sample points in potential planting areas are generated. The 'Tree Placement' module commences with a statistical analysis of existing trees to calculate the crown radius values of the majority of trees. New trees are assumed to develop a crown radius of the 75th percentile because larger trees can provide more benefits for biodiversity and enhance ecosystem services [6]. Consequently, the minimum distance between two points is set at least twice the statistically derived radius value when generating sample points. To illustrate the efficiency of this methodology, a case study in Munich is employed to identify suitable planting locations.

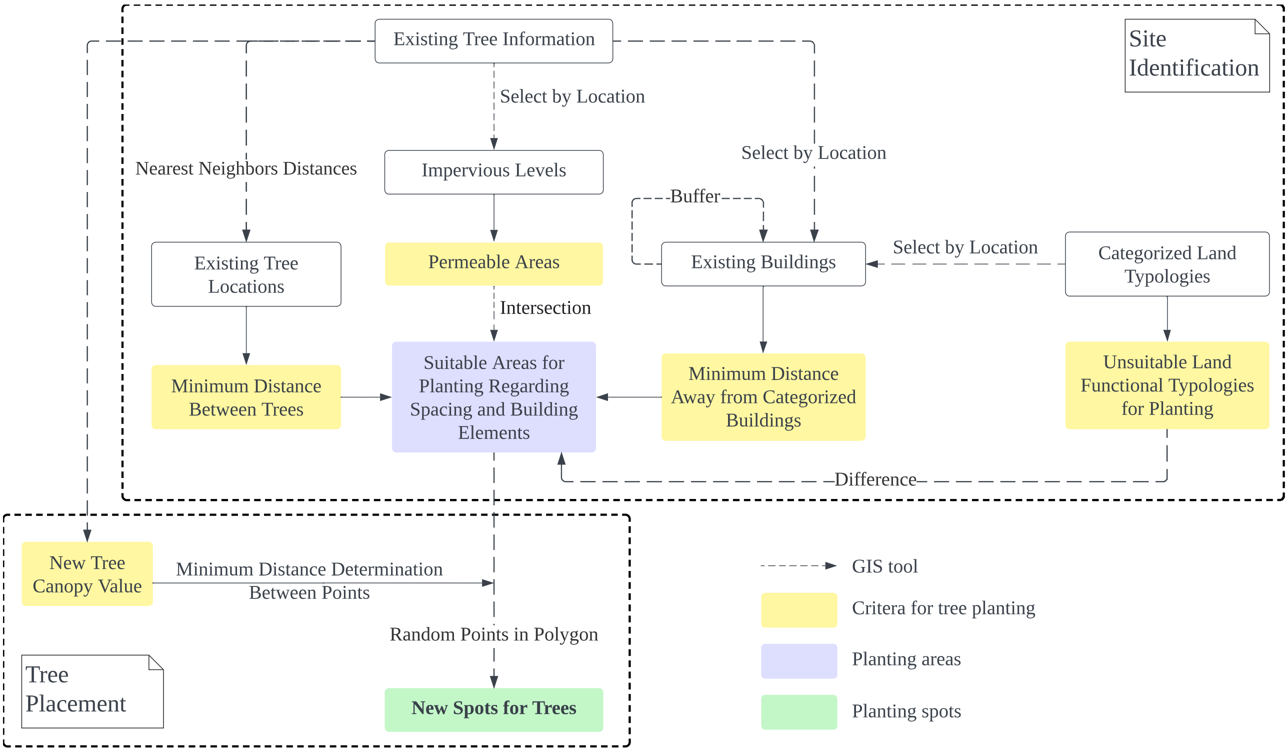

Figure 1: Flowchart of the proposed tree planting methodology

3.1 Data Preparation

Data is gathered and prepared involving the following steps:
(1) Existing Tree Information: Gather data on existing trees' locations and crown radii in Munich. This data is the basis for tree geometry and tree distance analysis. It is received from [7].
(2) Imperviousness Levels: Obtain data on imperviousness levels (imperviousness density) from the Copernicus website, with a resolution of 10 meters by 10 meters [8]. This data allows to integrate the extent of non-permeable surfaces in the area.
(3) Existing Buildings: Gather information on the locations of buildings for the subsequent analysis [9].
(4) Categorized Land Typologies: Collect data on different land typologies to categorize various land uses and identify functional areas unsuitable for planting. The urban typology is received from [10].

3.2 Spatial Analysis

3.2.1 Impervious Surfaces Analysis

Urban trees are surrounded by impervious surfaces, which impact their growth and function [11]. Here, the distribution of trees relative to different levels of imperviousness is assessed, providing insights into the interaction between urban greenery and non-permeable urban surfaces.

3.2.2 Building Proximity Analysis

The buildings are categorized by their land use typologies into four labels. A spatial join is performed between the buildings and land typologies, assigning each building the appropriate label. The details are presented in Table 1. Subsequently, buffers around each labeled building are created. The buffers increment from 0 to 6 meters in steps of 0.01 meters. This process enables the assessment of the variation in tree density with increasing distance from buildings in different categories. The evaluation aims to identify the minimum distance from buildings for suitable tree growth.

Table 1: Tree counts by land use typology

Label	Land Use Typology	Tree Count
A	Housing block trees	295,464
B	Street trees	19,089
C	Urban green spaces	11,169
D	Industrial-business trees	4,464

3.2.3 Tree Pair Proximity Analysis

A matrix distance analysis is performed on existing trees to identify the spatial proximity of the nearest neighboring tree for each individual tree, subsequently pairing them together. By analyzing the distribution and counts of these pairs, we aim to determine the suitable distance between two trees so that the individual tree canopies do not overlap excessively.

3.3 Statistical Analysis

3.3.1 Impervious Surfaces Analysis

The relationship between impervious levels and tree counts is examined in Figure 2. Scatter points represent tree counts at varying impervious levels. A sixth-degree polynomial is fitted to the data points to model this relationship. Additionally, the 75th percentile of tree counts is calculated and represented by a horizontal dashed line, establishing a threshold. This threshold is employed to identify impervious levels below which the surfaces may be suitable for planting areas. Excluding data at the 0 % impervious level, the graph indicates that impervious levels below 81 % frequently occur in the existing data.

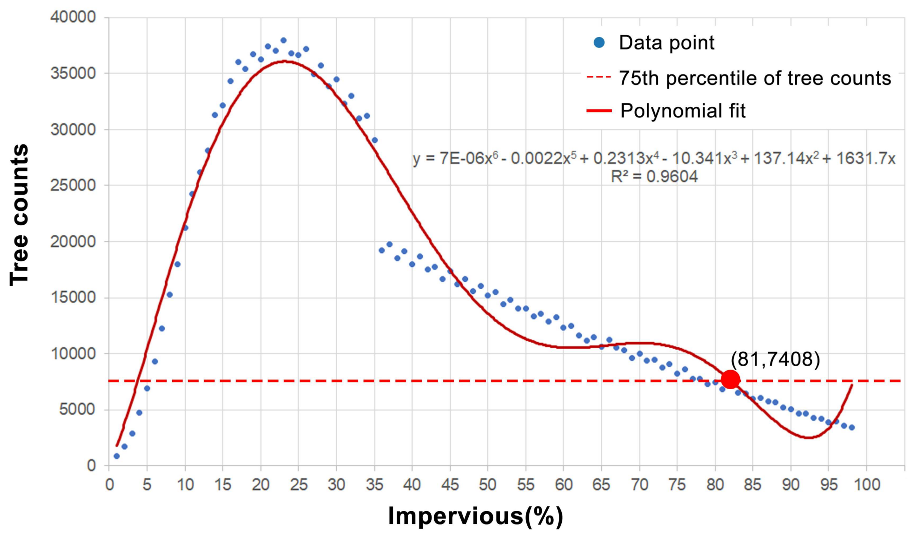

Figure 2: Tree counts in different imperviousness levels

3.3.2 Building Proximity Analysis

For labeled buildings, we focus on categories A, B, and D. For category A, we plot scatter points representing tree counts in each buffer ring. This shows that there is an increasing tendency in tree counts with increasing distances from the buildings, as depicted in Figure 3. To derive a threshold, we depict the rate of change in tree counts with increasing distance. Therefore, we plot the gradients between neighboring distance rings and smooth the trend of these changes, as shown in Figure 4. At a distance of approximately 0.91 meters, the rate of change in tree counts reaches a significant peak, suggesting this distance as suitable for tree planting. The same statistical methods are applied to categories B and D. For category B, the optimal distance is approximately 0.88 meters, and for category D, it is approximately 0.96 meters.

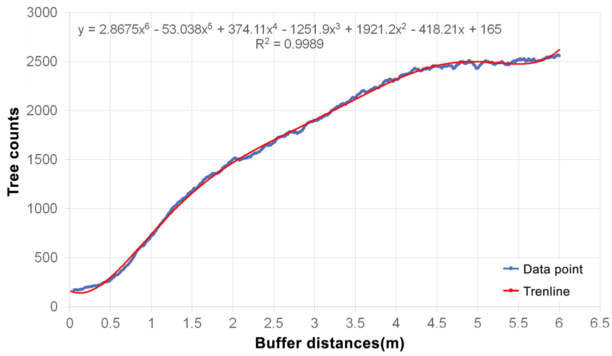

Figure 3: Incremental tree counts per 0.01 meter buffer distance for category A

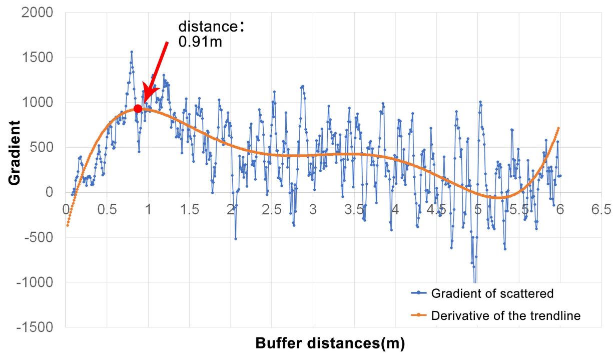

Figure 4: Gradient of tree counts change for category A

3.3.3 Tree Pair Proximity Analysis

To more accurately represent the relationships between tree pairs, we use the empirical cumulative distribution function (ECDF) plot (Figure 5) to describe the proportionate change as the distance between trees increases. We calculate the probability density of the ECDF (Figure 6) to identify the point of highest gradient increase. The peak probability density is observed at a distance of 2.97 meters.

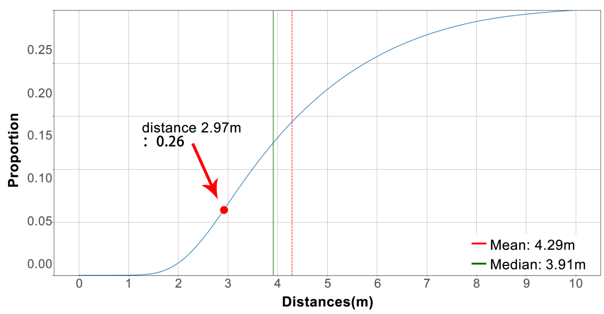

Figure 5: Distribution of nearest neighbor distances up to 10 meters

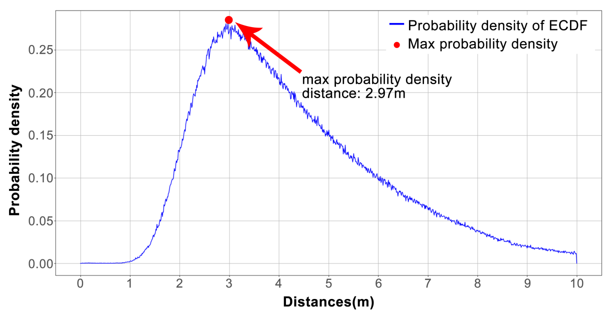

Figure 6: Probability density of nearest neighbor distance ECDF

3.4 Result for Site Identification

The comprehensive spatial and statistical analyses provide empirical rules for identifying potential tree planting areas. These are synthesized as follows:

- **Permeable areas**: The analysis indicates that areas with up to 81 % imperviousness can still support a significant probability for tree planting. In our case study, this threshold can serve as a criterion for identifying suitable permeable surfaces for tree planting.
- **Building proximity**: The optimal distance for tree planting varies by building categories. Overall, the ideal planting distances are between 0.88 meters (category B), 0.91 meters (A), and 0.96 meters (D). These distances help prevent damage from roots and branches while ensuring sufficient space for trees to grow [12].
- **Tree proximity**: The analysis suggests that the optimal spacing between tree pairs should be approximately 2.97 meters. This spacing ensures from a statistical perspective, that the trees in the new planting area do not overlap with the previous trees.

3.5 Results for Tree Planting

We apply the derived rules in an 85,000 m^2 study area in Munich to identify possible planting locations. For this purpose, the rules are translated into filtering functions in GIS. Additionally, it's essential to exclude certain functional typologies, such as roads, bicycle lanes, expressways, and water areas. This allows for a more accurate assessment of suitable planting locations.

To determine the expected crown radius of new trees, a statistical analysis of existing trees in Munich is conducted. The radius value at the 75th percentile is selected as the optimal choice because larger trees can provide greater benefits for biodiversity and enhance ecological functions [6]. Therefore, the resultant radius value for the new tree is standardized to 3.44 meters.

When generating sample points in potential planting areas using the GIS tool, the minimum distance between two points should be 6.88 meters. Upon completion of the above process, 103 generated points are observed. Figure 7 signifies the potential locations for tree planting within the specified case study area.

4 Discussion and Conclusion

This research introduced a GIS-based methodology to identify the most suitable locations for tree planting in urban areas, using Munich as a case study. The approach utilizes above-ground data, such as existing tree locations, imperviousness levels, and building locations, to avoid the common barrier of lacking detailed underground infrastructure data.

The methodology demonstrated its potential for enhancing urban greenery planning. The identified number of 103 planting locations in an area of 85,000 m^2 is comparable to the study of Kirnbauer et al. who found a potential of 141 and 123 large tree locations in an area of 68,500 and 55,400 m^2 [4]. Investigating the placement of trees based on empirical data and spatial analysis offers an extensible framework for cities aiming to expand their urban forests. Thus, urban planners should implement a practical, data-driven framework to increase canopy cover, thereby enhancing urban resilience against environmental challenges such as heat islands and air pollution [13]. This GIS-based approach provides a more precise decision-making process than alternative methodologies for identifying tree

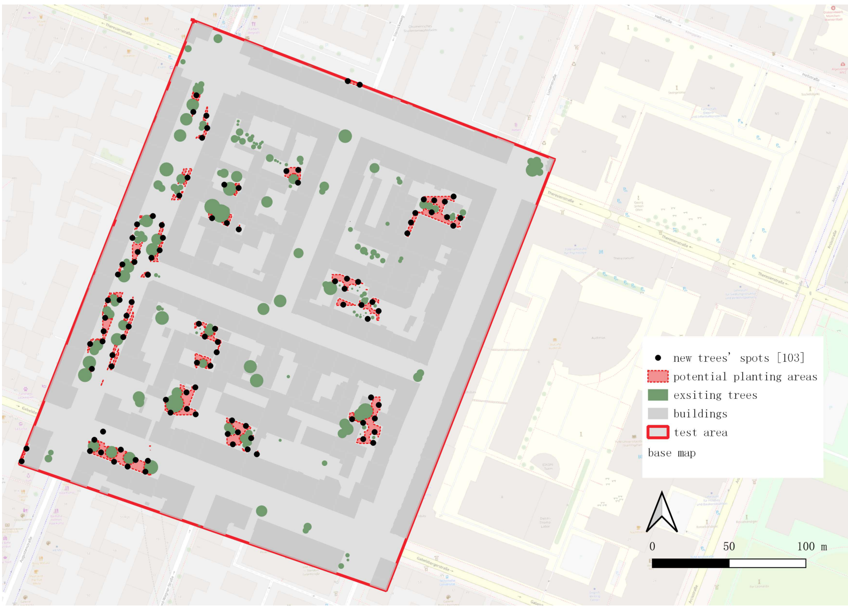

Figure 7: Identified tree locations by applying the methodology

locations that rely on underground data and user input. It uses a quantifiable and scalable method to assess the suitability of tree planting across various datasets, enhancing resource allocation and planning efficiency. However, this methodology has several limitations. It relies heavily on data availability, with the accuracy of impervious level division and land classification significantly influencing results. The accuracy level of impervious data is 10 meters, which can be large compared to the size of small districts. Inaccurate land classification could lead to misplanting trees. Additionally, only standardized trees were considered when generating sample points, ignoring different tree sizes. The reliance on existing datasets might bias the analysis towards well-surveyed areas, potentially overlooking newly urbanized regions or those with poor data coverage.

Future work should focus on integrating more multidimensional data and validating the methodology in various urban environments. Additionally, developing a more comprehensive approach tailored to different urban conditions is essential, as potential benefits provided by urban greenery heavily depend on the above and below-ground conditions in which trees are growing. Implementing machine learning models could further enhance the predictive capability of this methodology [14].

In conclusion, this study provides a framework for identifying urban areas suitable for tree planting that enhance ecosystem services while addressing the challenge of lacking underground data.

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