The Spatial Distribution of Tree Populations and Its Policy Drivers in Medieval Areas of Cities. Case Studies From East-central Europe

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Abstract

Trees in the densely built-up historical cores of cities play an important role in increasing the aesthetic values of the cityscape as well as lowering the effect of the urban heat island. The research aimed to determine the spatial distribution of tree populations in the medieval parts of cities according to local policy. The investigation included three cities in Central and Eastern Europe: Poznań and Lublin in Poland and Lviv in Ukraine. The oldest parts of these cities share similar origins, the same continental biogeographical region, and comparable climatic conditions.

This study considered indicators of occurrence, density, species composition, and spatial distribution; and the number of trees planted since the political transition to democracy has also been considered, taking into account the composition of their species. Local policy documents on greenery management, revitalisation, and adaptation to climate change were analysed.

The study identified different types of management concerning trees. In Poznań, trees are actively introduced in public spaces, but private backyards are managed by their owners. In Lublin, although there are relatively few new plantings, there is the largest share of trees in the backyards and self-seeding is common. In Lviv, there are new plantings in private and public spaces. Lviv is distinguished by its large share of native trees, with naturally shaped crowns, and in Poznan and Lublin, new plantings include artificially shaped, small spherical crowns. The local policy documents don't contain operational directives regarding the cultural, environmental, social, and technical conditions for new planting.

Introduction

The historical areas of cities are currently more oriented towards services for visitors than services for residents. A high density of cultural heritage sites attracts tourists and a growing number of catering establishments and shops being created for the benefit of visitors. This is particularly true in the intensely built-up, oldest parts of cities, where the spatial layout and many buildings were constructed in the Middle Ages. The management and planning of the historical parts of cities is a growing challenge (Bruce and Creighton 2008).

The public spaces of streets and squares are subject to competition between pedestrians, vehicles, and the owners of premises who want to use them for catering services. At the same time, there is great pressure to renovate or build new facilities. The permeable surface covered with vegetation, including trees, is therefore relatively small. There have been increased restrictions on cars in recent years, which has pushed vehicles outside the oldest part of the cities. This has created an opportunity to change the structure of the public space by introducing trees and other elements of green infrastructure.

In the rich literature regarding the role of trees in cities, few studies focus on the oldest parts of cities, which are characterised by high building density and high cultural values which have resulted in an intense tourist traffic, and the associated wide range of services, especially catering. These characteristics also result in an ambivalent attitude towards the presence of trees, especially along the streets (Mullaney et al. 2015).

Trees provide economic, social, health, visual, and aesthetic benefits to cities (Roy et al. 2012). Research documents the role of trees and greenery in compact urban developments in reducing the urban heat island effect (Bowler et al. 2010, Gillner et al. 2015. Norton et al. 2015). On the other hand, trees in a compact urban built-up area have disadvantages, including maintenance costs, light attenuation, infrastructure damage, and causing allergies (Avolio et al. 2015).

In the Middle Ages, trees played only a marginal role in cities. There were some trees in the private gardens of the ruling class and monastery gardens, but they were mostly fruit trees, rather than ornamental trees (Lawrence1993).

Taking into account the limited number of trees in the densely built-up historical parts of cities, the question is: to what extent is this due to the lack of unpaved surfaces and to what extent is it a result of local policy on greenery. This research aimed to determine the species structure of trees and their distribution against the background of the spatial structure of medieval parts of the cities under investigation. Trees planted in the last three decades were identified, which allowed us to assess the actual contemporary attitudes of decision-makers to trees against the background of local policy documents in the studied cities.

To capture the similarities and differences in the tree policies of different cities, comparative studies were conducted in Poznań and Lublin in Poland and Lviv in Ukraine. These are East-Central European cities established during the Middle Ages under the Magdeburg Rights in the 13th to 14th century (Poznań - 1253, Lublin - 1317, Lviv - 1356) when they were part of the Kingdom of Poland. At that time, the type of location, which defined the organisation of the city's self-government as well as being a planned, regular layout of streets with dense buildings, was very popular (Lück 2014; Szende 2016; Sakun et al. 2019). This has left its mark on the spatial structure of contemporary development and helps to compare the number and distribution of trees against the urban fabric. These cities are situated within the same continental biogeographical region (European Environmental Agency 2016), which means the same set of native species. The similarity in the climatic conditions of the cities under study (Table 1 *near here*).

Methodology

Study sites

Contemporary Poznań is the Polish city of an agglomeration with approximately 900,000 inhabitants. There are nearly 540,000 inhabitants within the administrative borders of the city, an area of 262 km^2 (Statistical Office in Poznań 2019). The city lies in the Middle European Lowland, along the Warta River. Poznań was an important political and religious centre in the second half of the tenth century. In 1253, the new city was established on the left bank of the Warta River under the Magdeburg Rights. It is estimated that in the fifteenth century there were no less than 4,000 inhabitants (Gąsiorowski, 1988). The oldest picture of Poznań (Braun and Hogenberg, 1617), shows the buildings and regular layout of streets within medieval walls from its northern perspective. An analysis of this picture reveals that trees are drawn inside almost all quarters of the buildings. The picture also depicts some backyards with signatures crops,

probably vegetables. There were no trees seen along the streets or in the central square, which, was perhaps due to their communication and commercial functions. The medieval city covered an area of nearly 22 hectares, the layout of streets has remained almost unchanged, despite the demolition of nearly all the former initial buildings and city walls.

The medieval part of the city is currently inhabited by approximately 3,000 permanent residents (based on evidence of the houses and attributed residents, Główny Urząd … 2016), which shows that the population has remained more or less stable from medieval times. Some 1.5 million tourists a year today visit Poznań, however, the oldest part of the city is the biggest attraction and the gastronomic centre. Car traffic has been eliminated from the area of the Old Market Square and several adjacent streets, and the remaining streets are limited to local traffic.

The Lublin agglomeration in Poland is inhabited by over 650,000 people. Within the administrative borders of the city, there are approximately 320,000 inhabitants in an area of 147.5 km^2 (Statistical Office in Lublin 2019). The city is situated on hills cutting through the valley of the Bystrzyca River and its tributaries. A settlement complex was originally formed on five hills near the confluence of rivers. The town charter under the Magdeburg Right of 1317 regulated the town's layout and method of governance. The newly established town was inhabited by about 2,500 people in the 14th century (Szczygiel 2017). Dense buildings meant that only small clusters of trees were found in the Dominican and Jesuit monastery areas and near the castle (Fijałkowski and Kseniak 1982; Lerue 2016). Vegetation, including single trees, could be found in courtyards. Small street sizes, the communicational and commercial function of the streets, and the central square lead to the assumption that there were no trees in the medieval city. In paintings from the seventeenth century depicting the appearance of the city, there is no high greenery within the walls, although vegetation is visible just outside the walls in the monastery gardens. Photographs from the second half of the 19th and early 20th centuries record the noticeably higher number of trees than presently occurs in the medieval area of Lublin. The medieval city covered an area of seven hectares, and the layout of streets has remained almost unchanged, despite the demolition of nearly all initial buildings and city walls. Currently, renaissance buildings prevail.

The current population is similar to that of medieval times: the inhabitants of this part of the city, according to official data, is estimated at 2,400. Over 1 million people, for whom the oldest part of the city is the main attraction, visit Lublin annually. Car traffic has been eliminated from the Market Square and several adjacent streets, and the remaining streets are limited to local traffic.

Contemporary Lviv is the largest agglomeration in western Ukraine with a population of about 800,000. The administrative area of the city covers 182 km^2, where about 725,000 people live (Derzhavna sluzhba statystyky Ukrainy 2019). Lviv is situated on the European watershed separating the Baltic and the Black Sea basins. The medieval part of the town is situated in the Peltwa River Valley, to the east of its riverbed, which is now included in an underground channel.

According to Zubrzycki's (1844) estimation, some 4,000 people were living in the city centre of Lviv in the early fifteenth century. Compared to medieval times, the population has therefore increased slightly; and some 2.2 million tourists visited Lviv in 2018.

An analysis of the oldest map of Lviv from 1777 (Atlas ukrainskykh istorychnykh mist 2014) reveals that only one tree was marked within the inner walls of the medieval city. Other trees appear to be located in the zone between the inner and outer city walls and other peripheral parts of the city. This can also be seen in maps and watercolour paintings from the eighteenth and nineteenth centuries. The lack of greenery within the boundaries of the medieval town results from the subordination of its spatial structure to residential, craft, and commercial functions. Gardens with fruit trees can be distinguished in the northern area of the city, within the inner boundaries of medieval Lviv, and only on the map of 1849 (Kadastr Lvova 1849).

The area of medieval Lviv within the inner walls covers 17.9 hectares. The layout of current streets and buildings has remained almost unchanged, despite the demolition of the former city walls. Car traffic has been eliminated from the Market Square and adjacent streets and remains unrestricted on the peripheral streets.

Methods of investigation

The research covered an area limited by a range of internal walls of the medieval cities. The course of the walls, which were depicted on historical engravings and archival maps, was superimposed on contemporary cartographic pictures, photographs, and satellite images. We started with an analysis of archival drawings, and studies of trees in cities. Although the oldest engravings cannot be treated literally, they were undoubtedly published as documentary material that gives an approximation of reality. Maps of the spatial distribution of the basic elements of urban fabric have been developed for the areas within the medieval walls, including buildings, sealed streets and areas, unsealed areas, and low greenery. Data for the maps was collected using the Urban Atlas database for Lublin and Poznań (European Environment Agency 2012), and using Google and Bing Maps images, supported by Open Street Maps for Lviv. The QGIS tool was used to process the data, which helped to calculate the proportions of the main elements of the urban fabric in the studied areas of the cities. Field research was conducted over two summer seasons in 2017 and 2018, which included the mapping of trees with their basic attributes (species name, size, age group). Due to the lack of source documentation on tree planting, non-invasive tree age assessment methods and age tables were used (Łukaszkiewicz 2010). Representatives of the planners and greenery managers in each city were interviewed. Spatial databases were created for trees in the individual cities. This helped to determine and then compare the tree saturation rate. The research was carried out in available public and private spaces (backyards), where permissions were obtained from the owners. The research included the identification of the species composition by native and non-native cultivated species or kenophytes in cases of self-sown trees (Rutkowski 2004, European Environmental Agency 2016).

Each of the specimens was assigned to one of the main types of locations within the city. Three aggregated categories were defined in the public space: streets/alleys, places/squares/pocket parks, and unmanaged greenery (rubble, bluffs). Private yards were distinguished as a separate group, but publicly accessible church areas were classified as parks. A distinction was also made between mature and younger trees, which were considered to have been planted after 1990, that is after the beginning of the political and socio-economic transition in both Poland and Ukraine. The results are detailed in tabular form for each of the studied cities, and a comparative analysis made.

Local policy documents were reviewed to determine the role of the strategic approach to greenery in the city, especially trees, taking into account the guidelines for the protection and shaping of green areas, revitalisation programmes, and climate change adaptation plans. Although the contents of the documents under consideration have different levels of detail and include fragmentary greenery issues, which allow for a comparison of the framework for the management of greenery in the different cities. Poznań has guidelines for the design, protection, and maintenance of street greenery (Zarząd Dróg Miejskich w Poznaniu 2019), and Lviv has a strategic document (Lvivska Miska Rada 2018), which also includes the upgrading of the public space. The *status quo* in Lublin is different, as it does not have any relevant documents, and the standards of protection and maintenance of greenery were analysed based on documentation prepared in connection with tenders for such works.

Poznań and Lublin have their own revitalisation programme (Rada Miasta Poznania 2017; Rada Miasta Lublin 2017) aimed at economic, social and cultural revival, an important element of which is to improve the quality of public space.
Climate change adaptation plans were analysed for Poznań and Lublin, made according to a similar scheme, and adopted as official papers (Instytut Ochrony Środowiska, 2018a, b). The relevant document for Lviv was prepared as an independent expert report, which did not become formally binding (Shevchenko and Vlasiuk, 2015).

These documents were used to identify the principles and standards of shaping greenery as an element of the city landscape, including the planting of trees. The authors as experts also participated in the dialogue with representatives of the greenery management units, which helped to enrich the collected research findings, given their own experience.

Results

Urban fabric

The city areas studied are characterised by the presence of similar elements in the urban fabric. Spatial patterns are similar in Poznań (Fig. 1) and Lviv (Fig. 3) with a regular layout of perpendicular streets that extend from the central square. The urban fabric of Lublin is a bit different (Fig. 2), where the streets run from the former castle and are connected by parallel blocks forming a fan layout. The spatial specificity of the old Lublin is not unrelated to the location of the city in the area of the former settlement structure and reflects a more diversified relief.

The hermetic development of the frontages of the quarters formed by the streets facing the central square in four directions is a characteristic feature of the spatial structure of the medieval part of Poznań. [*Fig.1 near here]* The buildings cover 45% of the area, and fortified streets and squares 35%. Unlike in the other two cities, there are large unpaved areas within the built-up quarter. On the outskirts, there are larger areas overgrown with managed green. The total area of unpaved surfaces occupies 20% of the studied part of the city. The spatial distribution of trees is more dispersed in Poznań than in the other cities.

The area of medieval Lublin is the smallest of the cities under consideration *[Fig.2 near here]*. Slightly more than half of the area is covered by buildings (52%), and sealed squares and streets occupy 43%. The area of greenery, only 5%, is concentrated in three larger fragments. The distribution of trees is more concentrated in Lublin than in Poznań and Lviv.

Currently, in Lviv, 54% of the area is covered by buildings, and 43% of the area is sealed streets and squares. *[Fig.3 near here]* The proportions of the main elements of land cover are almost identical to those in Lublin, while the spatial layout of the medieval city is very similar to that of Poznań. The remaining impervious areas are mostly in the peripheral parts.

The structure of land cover is similar in the city areas in this study, which results from the preservation of the historical urban shape (Fig. 4). *[Fig.4 near here]* Poznań has a certain distinctiveness, where larger biologically active areas have survived on the outskirts and inside quarters of buildings, which together occupy almost 20% of the area. There are also two unsealed plots of land in Poznań, which are presently used as car parks. In Lublin and Lviv, the unpaved surfaces are in small scraps of areas that do not significantly affect the structure of the land cover.

Species composition

In Poznań (Table 2.) *[Table2. near here]*, native *Acer platanoides* prevails out of 24 identified species and accounts for 40% of all the trees. The large proportion of this species results from new plantings (since 1990). A subdominant position is held by non-native species *Aesculus hippocastanum* and *Robinia pseudoaccacia.* These three species together make up some two-thirds of all the trees in the medieval section of Poznań. They are found mainly in streets and squares, but *Aesculus hippocastanum* is the most common species in yards. *Robinia pseudoaccacia* owes its abundance to its resistance to urban stress and the planting of 13 specimens as street trees in recent decades. Trees of other species occur in Poznań individually or in groups of several specimens.

Lublin trees are characterised by high species diversity; 85 specimens in total were assigned to species (Table 3.0). *[Table3.near here]* The three most numerous ones, *Acer platanoides* (15), *Robinia pseudoaccacia* (10), and *Sambucus nigra* (8), together account for about 35% of the total number; there are no clearly dominant species. The greatest diversity is found in the backyards, where ornamental trees and shrubs are planted; in these areas, short-lived, non-native tree species dominate. Self-seeding specimens (*Sambucus nigra*) can also be found in the backyards.

Lviv trees are characterised by a significant share of noble long-lived trees belonging to native species (Table 4.). *[Table4.near here]*. The most numerous of them are *Tilia cordata* (47), *Acer platanoides* (23), *Fraxinus excelsior* (21), which, together with other native, cultivated species, account for over 60%. They are a valuable component of the greenery in this part of the city because, in addition to their aesthetic qualities, they are resistant to the stresses of the urban environment. Among other planted species, *Thuja occidentalis* (42) is the most abundant ornamental evergreen tree, probably because it is easy to care for. Of this group, *Aesculus hippocastanum* (12) and *Prunus domestica* (10) are also found in significant numbers.

The most common species of trees across the cities is *Acer platanoides*. Another feature the cities have in common is a lack of fruit tree species (excluding some low valued *Prunus domestica*), which implies a complete change in the function of the trees compared to preindustrial periods.

Age of trees

The differences between the cities reveal a different approach to the introduction of tall, new greenery into the built-up areas (Fig. 5) *[Fig.5 near here]* The proportion of younger trees (up to about 30 years old) is highest in Poznań (45%), although it is only slightly lower in Lviv (40%). In Lublin, mature specimens dominate, and younger specimens comprise only about 22%.

Younger specimens of *Robinia pseudoaccacia 'Umbraculifera'* have been planted in greater numbers in Lublin. Eight of those specimens are found in the town square by the theatre (in the less frequented part, close to the old walls) and four *Acer platanoides 'Globosum'* in the yards. Other trees are single specimens from seven other ornamental species, all planted in backyards. New plantings in Poznań, with single exceptions, also include *Acer platanoides 'Globosum'* (24 trees) and *Robinia pseudoaccacia 'Umbraculifera'* (13 trees), which were planted along two streets and in pocket parks and squares. The species structure of the new plantings in Poznań and Lublin shows that tree size is decisive in the choice of species, and native or non-native status does not play any significant role. In Lviv, about half of the new plantings are non-native *Thuja occidentalis*, which are predominantly found on church grounds.

Among the cultivated non-native species, there are also six trees of *Aesculus hippocastanum*, introduced as complementary plantings in the Market Square. A few younger trees of native species are found in Lviv (24 trees). Eight *Salix alba* were planted in the courtyard of the polyclinic, and seven *Crataegus levigata* were planted along one of the streets. Other single specimen species have been planted in the last few decades. Among them is *Robinia pseudoaccacia 'Umbraculifera'*.The analysis of the species composition of younger trees in the three cities shows that short-lived non-indigenous trees or ornamental forms of native species are planted.

Spatial distribution of trees

Despite the similarities in the spatial structure of the medieval parts of the cities, both the indicators of the number of trees per unit area as well as their distribution between different elements of urban space differ. The greater proportion of soil covered with vegetation in Poznań is in contradiction to the lowest tree saturation index. Lublin (13.0 trees/ha) and Lviv (11.3 trees/ha) had a twofold greater tree saturation index than Poznań (5.9 trees/ha). Differences between the cities in the total number of trees are not reflected in the variety of the observed tree attributes. The spatial distribution of trees between public and private space is very different. Each city has a specific spatial distribution of trees, as illustrated in Fig. 6. *[Fig.6 near here]*

Poznań has the most balanced distribution of trees between different locations. Compared to the other two cities, it is distinguished by having the highest share of street trees. This is the result of planned planting trees along two selected streets in recent decades. In Lviv, there is a slightly higher density of trees in similar locations, whereas in Lublin the share of trees along traffic routes is marginal, but a significant percentage are grouped in the Cathedral and Theatre Squares. Lublin is distinguished by having the highest proportion of trees in its yards. This indicator is almost three times higher than in Poznań and six times higher than in Lviv. This shows a higher proportion of outbuildings used in Lublin for housing purposes and higher standards of backyard care.

In Lviv, there is a small proportion of trees in yards (9%), which is related to the high proportion of the sealing area within building quarters. In Lviv, 67% of the trees are located on squares and plazas. This is a distinctive feature of the city: a significant number of trees growing in church grounds and monastery yards, which have traditionally been a place for burials and garden crops, can be considered a factor conducive to a larger number of trees. There are also many trees in the Old Town Square. This is related to the policy of the municipal authorities to preserve the historical features of the landscape in this part of the city, including trees (Lvivska Miska Rada, 2018). The markets in Poznań and Lublin are completely devoid of trees, although there is a considerable number in plazas and pocket parks. In Poznań, this accounts for nearly 31% of the trees, which are mostly located on peripheral squares. In Lublin, trees in this location account for 26%, and most grow in squares near the cathedral and at the theatre.

Local Policy

Analysis of local policy documents shows that they are similar in the sense that they indicate the need to restore trees, introduce new greenery, and protect existing greenery. All documents ascribe great importance to creating even small patches of greenery such as pocket parks and green backyards, especially in areas where greenery is lacking and UHI exposure is highest. However, there are no specific guidelines for historic spaces even in revitalisation programmes. In general terms they indicate that each activity in the downtown must be based on the history and tradition of the place. The value of historic buildings should be taken into account and the historical heritage respected.

Generally speaking, it can be said that local policy documents offer a wide range of possibilities for action, but do not specify detailed conditions for introducing high greenery to compact buildings. Only the guidelines for Lviv recommend two varieties of beech *(Fagus sylvatica purpurea 'Atropunicea', Fagus sylvatica pendula)* for backyards in the old town. For Lublin, there is an indication that the tree species structure needs to be recreated by eliminating brittle species. The guidelines for Poznan require that the appropriate selection of species for a particular object is applied and that unproven plants are not used. When selecting plants, the soil and climatic conditions, as well as those resulting specifically from the urban conditions, should be taken into account, as well as the location of existing and planned underground utilities. These general formulations have not yet been developed into operational directives.

The review shows that the local tree policies leave a very large scope of freedom for the institutions managing greenery in the examined cities. Such a conclusion is fully consistent with the fact that despite similarities in the urban fabric, there are significant differences in the attributes of trees planted in the medieval parts of the cities under study. Each city represents a different type of approach to trees within its medieval sector:

a) Active in public space and passive in private space - represented by Poznań, where nearly half the trees are new, located in public spaces, along selected streets and squares. Planting in private spaces rarely occurred.

b) Restrictive in public space and permissive in private space - represented by Lublin, where there are numerous plantings within yards as private spaces and far-reaching restrictions on introducing and restoring trees into the public space.

c) Non-restrictive - represented by Lviv, where there is a high proportion of new plantings in private plots near churches and public spaces as well.

Discussion

The number of new plantings (since 1990) was not high for any of the cities in this study, which shows that the policymakers do not favour an increase in the amount of greenery in cities. This is supported by the lowest tree density index in Poznań, which also has the highest proportion of soil covered by greenery. Kronenberg, (2015) points to the role of bureaucratic barriers in introducing trees to the heavily invested parts of the urban fabric. The practice in the studied cities is contrary to research findings that the cultural history of an area is positively related to its green quality and, in turn, to public health (Weimann et al. 2017).

Among the trees planted in recent decades, there is a clear dominance of small decorative trees, grafted onto the trunks of *Acer platanoides 'Globosum'* and *Robinia pseudoaccacia 'Umbraculifera'*. This is unfavourable from an aesthetic and architectural point of view; the unnatural morphology of their crowns does not match the scale of the development or the character of historical spaces. Ameen et al. (2015) point out the advantages of sustainable urban design, which harmoniously combines the protection of historical heritage with the character and spatial distribution of green areas. The planting of small decorative tree forms has very limited natural-ecological significance compared to native forms (Gromke and Ruck 2007). These new forms of tree crowns are alien to the landscape of historic parts of cities.

The results of previous studies document the environmental benefits delivered by trees, including the cooling effect, depending on tree size and foliar density (Georgi and Zafiriadis 2006; Tan et al. 2016). This is also recognised in cities in the UK, where the planting of large tree species is promoted because the leafy area is crucial for the real benefit of trees (Armour et al. 2012). The claim that the reduction in the planting of large trees is due to the lack of space and the existence of underground infrastructure should be criticised.

There are technical solutions and compensation systems (Morgenroth 2008; Mullaney et al. 2015) and proven species (Sjöman et al. 2018) to overcome these disadvantages. On the other hand, visual preference studies show that urban green structures should have several layers of vegetation that do not obstruct the view (Ebenberger and Arnberger 2019).

Many authors highlight the importance of different forms of urban agriculture (Mougeot 2000; Barthel et al. 2013; Lin et al. 2015), including the role of fruit trees (Lafontaine-Messier et al. 2016). This indicates a trend to increase the role of food production in cities, which was common in the past centuries.

Several authors have indicated that the type of greenery introduced into the urban environment should consider the opinions and preferences of visitors (Kirkpatrick et al. 2012; Arnberger and Eder, 2015,). In all the studied cities, the number of tourists exceeds the population of inhabitants. Other authors referring to green space management and the preferences of users in different Portuguese cities have pointed out the same aspect (Graça et al. 2018; Madureira et al. 2018).

Ottitsch and Krott (2005) have highlighted the unsatisfactory implementation of existing legislation, programs, and plans as one of the most significant weaknesses of urban green policies in Europe. Bourne and Conway (2014) reached similar conclusions when analyzing the distribution of trees in urban municipalities located in the Greater Toronto Area. This is confirmed by the results of this study. The local policy documents recognise the importance of trees for improving the city's climate, the aesthetics of heavily invested land, and the quality of life of its inhabitants, however, none of the cities surveyed have a coherent tree policy that would include specific targets for trees in densely built-up areas or directives on how to achieve the targets. Meanwhile, Bodnaruk et al. (2017) show that such documents should contain detailed guidelines that take into account the existing conditions and the ways of shaping green infrastructure adapted to them. Nowak et al. (2013) have shown that despite the intensive investment, there are areas where tree planting is possible and needed in the central areas of cities. This approach, however, requires the courage of both designers and decision-makers.

Conclusions

The Central-Eastern European cities in this study have similar spatial structure and natural conditions. This hasn't any important effect on the shaping of tall greenery resulting mostly from local management. Although the number of trees in each of the studied cities is small, their spatial distribution varied and did not depend on the size of the surface covered by vegetation. This applies both to the share of trees in private and public spaces as well as to the number of trees in different types of locations. The proportion of younger and mature trees is also different. These differences prove that the main driving force of tree distribution is local practice. Although cities have local climate policy documents as well as guidelines on the protection and care of greenery, they do not contain specific objectives or instructions on how to achieve them. As a result, there are large differences in the spatial structure, species, and age of trees. This applies, in particular, to the distribution and species composition of younger trees, which highlights the differences in the planting preferences of local authorities.

The results indicate that the existing trees mainly have aesthetic functions, with low ornamental trees predominating, which can also take the form of shrubs (*Crateagus leavigata, Sambucus nigra, Magnolia sp.*). Few species of tall and native trees were planted, especially, in Poznań and Lublin in recent decades. Against this background, Lviv has the highest proportion of native, taller species, which serves to preserve the historical landscape of this city.

A new trend of planting small trees, grafted onto the trunks of *Acer platanoides 'Globosum'* and *Robinia pseudoaccacia 'Umbraculifera'* and characterised by unnatural crown shapes, was observed in the studied cities, especially in Poznań and Lublin. This is aesthetically controversial and has no significant effect on climate change adaptation. There is a high proportion of native old trees in Lviv, but ornamental species dominate among the new plantings. This mainly concerns private spaces.

The research findings document the approach to high greenery management in Central and Eastern Europe, however, the conclusions provide a rationale for also improving local policy concerning trees in other regions with similar natural conditions.

The results of this study indicate the need to extend research further in densely built-up cities, as well as to consider the social and cultural aspects, especially concerning the perception of trees in the medieval parts of cities, by residents, tourists, and business owners. This is all the more important because climate change is forcing adaptation projects, among which nature-based solutions play a crucial role.

Declarations

We are pleased to submit a research article entitled ***The Spatial Distribution of Tree Populations and its Policy Drivers in Medieval Areas of Cities. Case Studies from East-Central Europe*** for consideration for publication in the Journal Urban Ecosystems.

We believe that this manuscript is appropriate for publication in this journal because the lessons learned from our study on the distribution of high greenery historical cities and its policy drivers could be of general interest. The results of the study can contribute to the understanding of regularities and peculiarities in this respect. Therefore, it can constitute a point of reference for cities having a similar spatial structure. We have done our best to conform the manuscript to the “Guide for Authors” for new submissions.

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Conflicts of interest/Competing interests We have no conflict of interest nor competing interest to declare

Availability of data and material Data from the field investigations and elaborated spatial data are available

Code availability not applicable

Authors' contributions We have made research alone and nobody, except us, has made a significant contribution to the conception, design, execution, or interpretation of the reported study

Ethics approval We declare that we respected ethical principles, although the eth-ics approval was not required. There were no external human participants in the research, and we did not use the data collected from human participants

Consent to participate We would like to ensure that this paper does not require any permission from other people to participate at any stage

Consent for publication We would like to ensure that this paper does not require any per-mission from other people to publish it in this form

This research was never published before. We have written entirely original work, and all the works of others we have used in the text have been appropriately cited.

On behalf of the Authors’ team

Poznań, 13 February 2021

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Tables

Table 1. Selected climatic conditions of research sites

Research site	The average temperature in January* [°C]	The average temperature in July* [°C]	The average annual rainfall* [mm]	Growing season
Poznań	-2.5	18.2	520	229 days**
Lublin	-5.6	18.5	540	215 days**
Lwów	-3.9	17.8	697	233 days***

Source: *https://pl.climate-data.org/; **Krużel, et al. 2015; ***Lviv, 2015.

Table 2. Trees and their attributes in the medieval part of Poznań

Species	Native, non-native cultivated species	Number of individuals	Age		Urban structural elements			
			younger	mature	streets/ alleys	places/squares/pocket parks	yards	unmanaged greenery
Betula pendula Roth.	native, cultivated sp.	1	1	-	-	-	1	-
Quercus robur L.	native, cultivated sp.	2	1	1	-	2	-	-
Carpinus betulus L.	native, cultivated sp.	4	-	4	-	4	-	-
Fraxinus excelsior L.	native, cultivated sp.	1	-	1	-	-	1	-
Aesculus hippocastanum L.	non-native, cultivated sp.,	24	-	24	15	-	9	-
Acer platanoides L	native, cultivated sp.	17	10	7	2	11	5	-
Acer platanoides 'Globosum'	non-native, cultivated sp.,	24	24	-	24	-	-	-
Acer saccharinum L.	non-native, cultivated sp.,	1	-	1	-	1	-	-
Acer campestre L.	native, cultivated sp.	8	8	-	8	-	-	-
Acer pseudoplatanus L.	native, cultivated sp.	1	-	1	-	1	-	-
Corylus colurna L.	non-native, cultivated sp	1	-	1	-	1	-	-
Tilia cordata Mill.	native, cultivated sp.	5	1	4	1	3	1	-
Tilia tomentosa Moench	non-native, cultivated sp.	1	-	1	-	1	-	-
Ginco biloba L.	non-native, cultivated sp.	1	-	1	-	1	-	-
Morus alba L.	non-native, cultivated sp.	1	-	1	-	-	1	-
Alnus glutinosae. L.	native, cultivated sp.	1	-	1	-	-	1	-
Juglans regia L	non-native, cultivated sp.,	1	-	1	-	-	1	-
Robinia pseudoacacia L.	non-native, cultivated sp.,	1	-	1	-	1	-	-
Robinia pseudoacacia 'Umbraculifera'	non-native, cultivated sp.,	-	13	-	9	4	-	-
Pinus ponderosa Dougl. ex C.Lawson	non-native, cultivated sp.	3	-	3	-	3	-	-
Rhus typhina L.	non-native, cultivated sp.,	1	1	-	-	-	1	-
Picea abies (L.) H.Karst	native, cultivated sp.	1	-	1	-	1	-	-
Thuja occidentalis. L.	non-native, cultivated sp.	1	-	1	-	1	-	-
Ulmus minor Mill.	native, cultivated sp.	1	-	1	-	1	-	-
Salix babylonica	non-native, cultivated sp.	1	-	1	-	-	1	-
Platanus hispanica Munchh	non-native, cultivated sp	1	-	1	-	-	1	-
Total		104	59	58	74	38	23	0

Source: Own investigations

Table 3. Trees and their attributes in the medieval part of Lublin

Species	Native, non-native cultivated species	Number of individuals	Age		Urban structural elements			
			younger	mature	streets/ alleys	places/squares/ pocket parks	yards	unmanaged greenery
Sambucus nigra L.	native, cultivated sp.,	8	2	6	-	-	6	2
Syringa vulgaris L	non-native, cultivated sp.,	1	-	1	-	-	1	-
Ailanthus altissima Mill.	non-native, cultivated sp.,	1	1	-	-	-	1	-
Betula pendula Roth	native, cultivated sp.	2	-	2	-	-	2	-
Taxus baccata L.	native, cultivated sp.	2	-	2	-	-	2	-
Prunus avium L.	native, cultivated sp.	1	1	-	-	-	1	-
Pseudotsuga menziesii	non-native, cultivated sp.	1	-	1	-	1	-	-
Quercus rubra L.	non-native, cultivated sp.,	1	-	1	-	1	-	-
Crateages monogyna. L.	non-native, cultivated sp.	4	-	4	-	1	3	-
Juniperus comminis L.	non-native, cultivated sp.	6	-	6	-	-	6	-
Sorbus aucuparia L.	native, cultivated sp.	1	-	1	-	-	1	-
Fraxinus excelsior L.	native, cultivated sp.	6	-	6	1	1	3	1
Aesculus hippocastanum L.	non-native, cultivated sp.,	1	-	1	-	1	-	-
Acer platanoides L.	native, cultivated sp.	11	1	10	2	2	7	-
Acer platanoides 'Globosum'	non-native, cultivated sp	4	4	-	-	-	4	-
Tilia cordata L.	native, cultivated sp.	1	1	-	-	1	-	-
Magnolia stellatea L.	non-native, cultivated sp.	2	-	2	1	1	-	-
Larix decidua L.	non-native, cultivated sp.	3	-	3	-	-	3	-
Morus alba L.	non-native, cultivated sp.	1	-	1	-	-	1	-
Robinia pseudoacacia L.	non-native, cultivated sp.,	2	-	2	-	2	-	-
Robinia pseudoacacia 'Umbraculifera'	non-native, cultivated sp	8	8	-	-	8	-	-
Rhus typhina L.	non-native, cultivated sp.,	4	-	4	-	-	4	-
Prunus domestica L.	non-native, cultivated sp.,	4	1	3	-	-	3	1
Picea abies (L.) H.Karst.	native, cultivated sp.	5	4	1	-	1	4	-
Ulmus minor Mill.	native, cultivated sp.	2	-	2	-	2	-	-
Salix alba L.	native, cultivated sp.	2	-	2	-	-	2	-
Thuja occidentalis	non-native, cultivated sp.	1	-	1	-	-	1	-
Total		85	19	66	4	22	55	4

Source: Own investigations

Table 4. Trees and their attributes in the medieval part of Lviv

Species	Native, non-native cultivated species	Number of individuals	Age		Urban structural elements		
			younger	mature	streets/ alleys	places/squares/pocket parks	yards
Betula pendula Roth	native, cultivated sp.	4	-	4	-	4	-
Fagus sylvatica L.	native, cultivated sp.	1	-	1	-	1	-
Prunus avium L.	native, cultivated sp.	2	-	2	2	-	-
Gleditsia triacanthos L.	non-native, cultivated sp.	3	3	-	-	3	-
Crateagus laevigata 'Paul's Scarlet'L.	non-native, cultivated sp.	7	7	-	7	-	-
Pyrus communis L.	non-native, cultivated sp.	1	-	1	-	-	1
Malus baccata Borkh.	non-native, cultivated sp.	1	-	1	1	-	-
Juniperus communis L.	non-native, cultivated sp.	1	1	-	-	1	-
Sorbus aucuparia L.	native, cultivated sp.	3	-	3	2	1	-
Fraxinus excelsior L.	native, cultivated sp.	21	3	18	15	5	1
Aesculus hippocastanum L.	non-native, cultivated sp.	12	6	6	4	8	-
Acer platanoides L.	native, cultivated sp.	23	-	23	7	16	-
Acer platanoides 'Globosum'	non-native, cultivated sp	1	1	-	1	-	-
Tilia cordata Mill.	native, cultivated sp.	47	1	46	1	46	-
Magnolia spp. *L.*	non-native, cultivated sp.	1	1	-	1	-	-
Juglans regia L.	non-native, cultivated sp	1	-	1	1	-	-
Robinia pseudoacacia L.	non-native, cultivated sp	1	-	1	1	-	-
Pinus sylvestris L.	native, cultivated sp.	1	1	-	-	1	-
Prunus domestica L.	non-native, cultivated sp.,	10	2	8	4	4	2
Picea pungens Engelm.	cultivated sp.	4	3	1	-	4	-
Populus alba L.	native, cultivated sp.	3	-	3	1	-	2
Salix alba L.	native, cultivated sp.	10	9	1	1	1	8
Thuja occidentalis	non-native, cultivated sp.	43	43	-	1	38	4
Total		201	81	120	50	133	18

Source: Own investigations

Figures

Figure 1

Main types of land cover in the area of medieval Poznań, including the spatial distribution of trees. The own elaboration Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

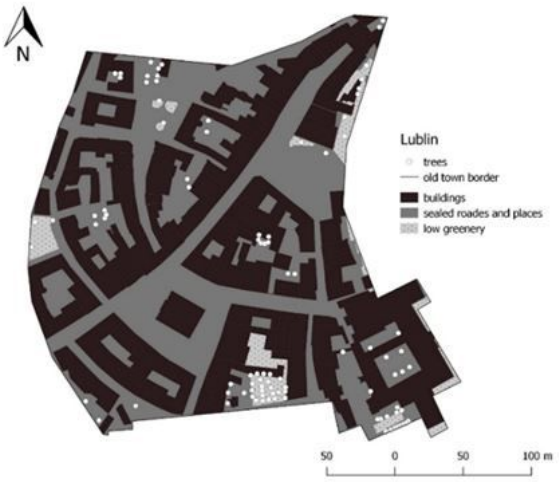

Figure 2

Main types of land cover in the area of medieval Lublin, including the spatial distribution of trees. The own elaboration Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal

status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

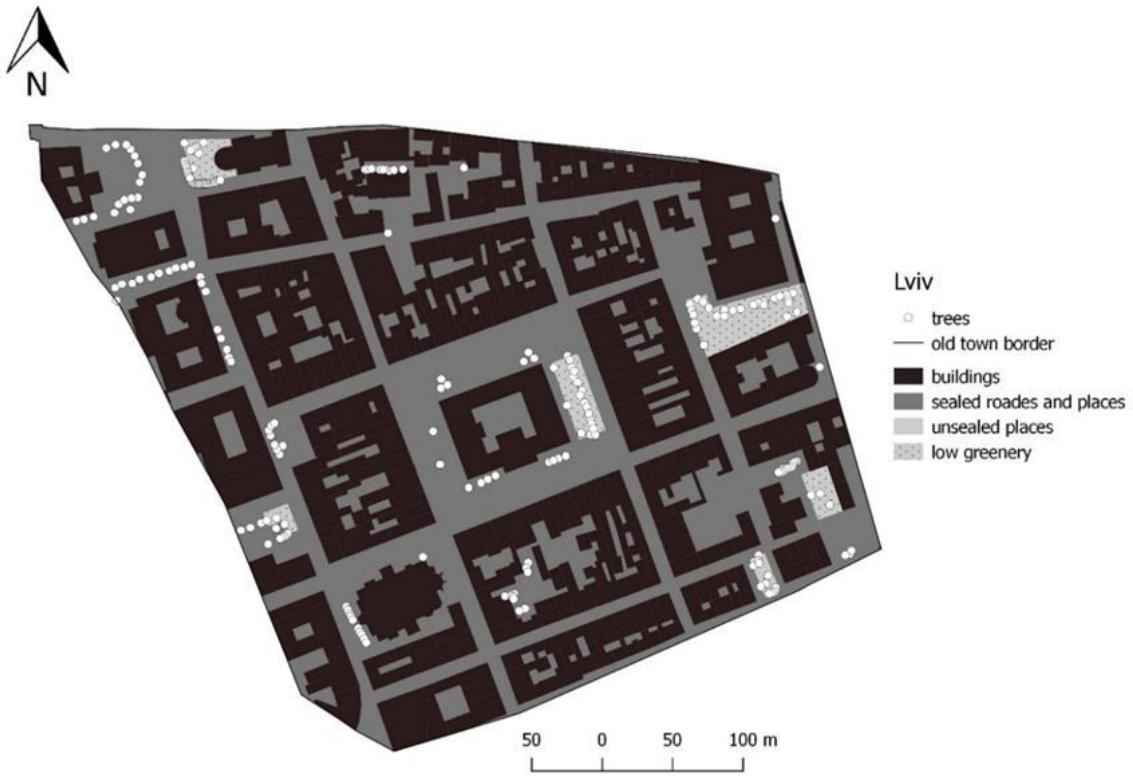

Figure 3

Main types of land cover in the area of medieval Lviv, including the spatial distribution of trees. The own elaboration Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

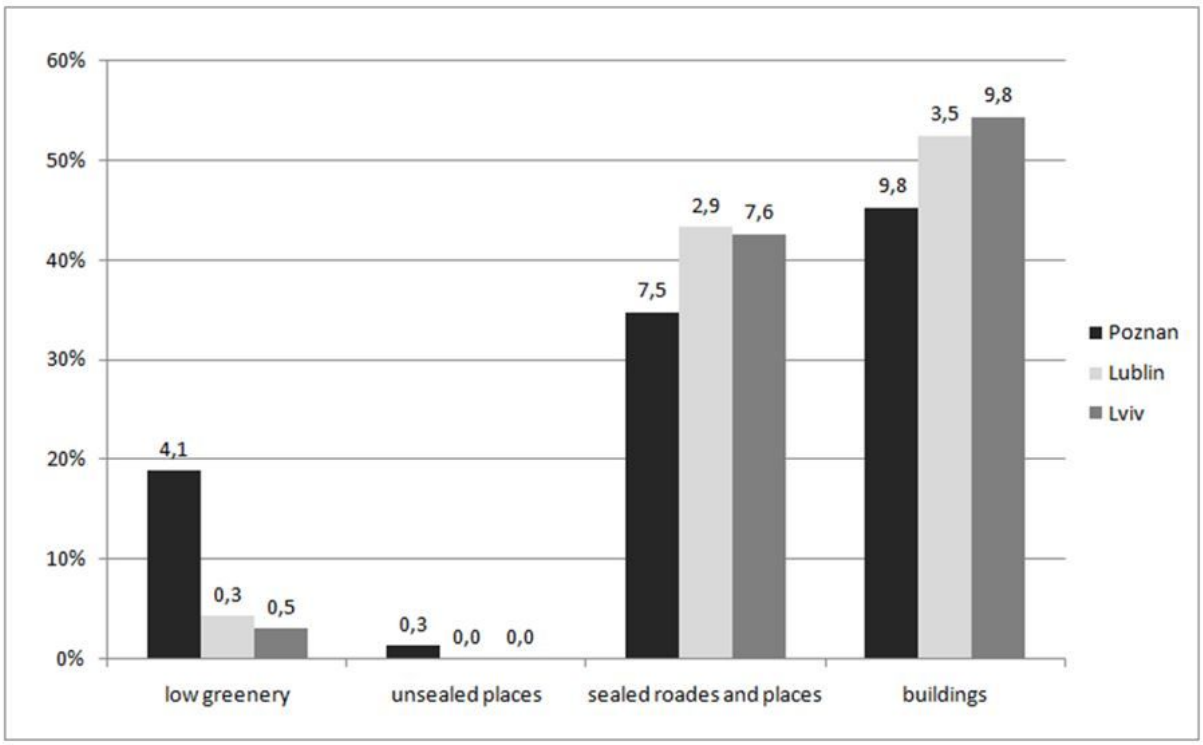

Figure 4

The main elements of land cover structure - comparison between Poznań, Lublin, and Lviv. The own elaboration. The numbers on the top of columns indicate the area (ha) of each land cover type.

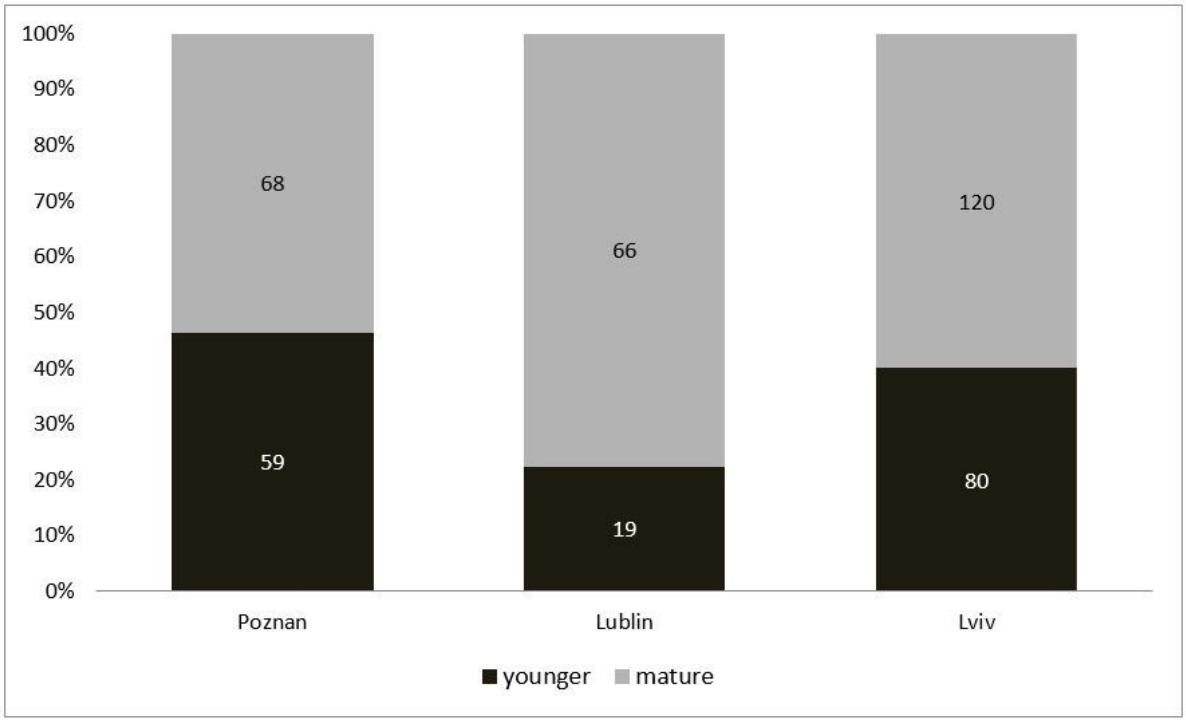

Figure 5

The proportion of mature and younger trees in Poznań, Lublin, and Lviv. The numbers on columns indicate the number of trees. The own elaboration

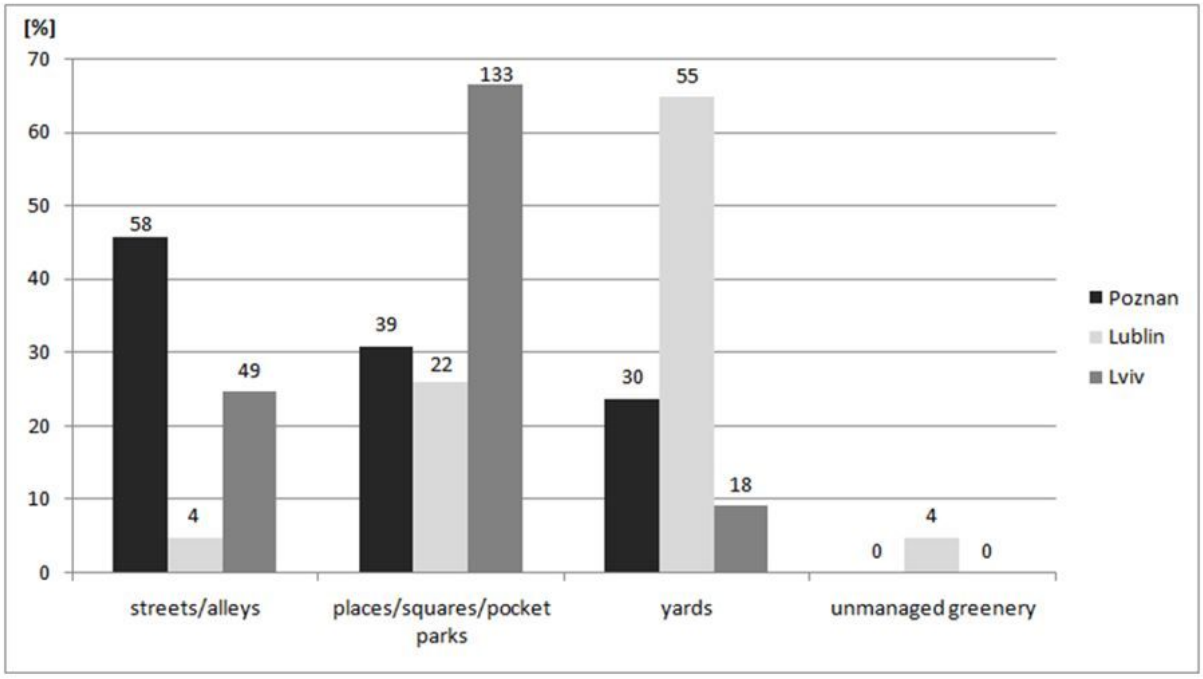

Figure 6

Distribution of trees according to aggregated urban structural elements in the considered parts of Poznań, Lublin, and Lviv. The numbers on the top of the columns indicate the number of trees. The own elaboration