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Trees of Cracow's Downtown Streets and Squares of Krakow as a Conservation and Environmental Problem

Drzewa śródmiejskich ulic i placów Krakowa jako problem konserwatorski i środowiskowy

Keywords: historical greenery, street trees, UNESCO, cultural landscape, conservation of monuments, vegetation dynamics

Słowa kluczowe: zieleń historyczna, drzewa uliczne, UNESCO, krajobraz kulturowy, konserwacja zabytków, dynamika roślinności

Introduction

Among the numerous conservation issues related to historic cities, street greenery is currently becoming crucial and seen as an indispensable element in improving the quality of life and the sustainability of cities. Trees not only form part of the lost historical landscape and enhance aesthetic value but also play an important role in alleviating environmental challenges. They are an essential element of urban design [Lawrence 2008]. The disappearance of trees from the landscape of historic cities indicates a need to protect, preserve, and reconstruct them. It is important to integrate greenery design and conservation with planning, and to develop urban strategies and species catalogs at urban and architectural scales.

This discussion focuses on trees that grow along the streets and in the squares in the center of Cracow, a historic city in Central and Eastern Europe, given the status of a UNESCO World Heritage Site in 1978 and placed under various forms of heritage conservation applicable in Poland. Our study covers the period between 1907 and 2023. The reference point for our comparative analysis of the number of street and square trees was a report published by municipal gardener Bolesław Malecki [1907]. The streets and squares covered by the report were planned and designed in different periods, featured differed uses, represented different types, and the number of trees concerns the year 1907, which allows a comparison with the state in 2023. Based on this data, we analyzed 48 streets and squares. These were not all of Cracow's green streets, as there were many more in the period leading up to the Second World War, due to urbanization, regulatory plans and the development of transportation, historical sources confirm. In 1881, the first streetcars appeared

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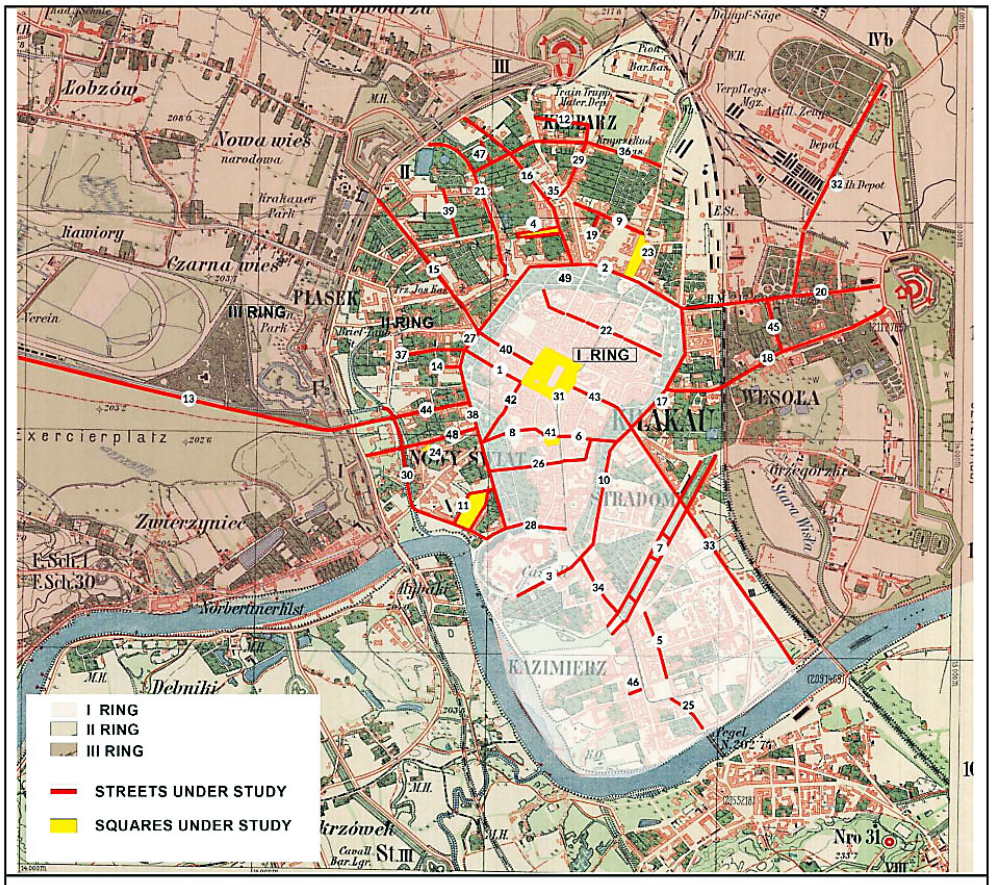
a

		szt.			szt.
1	ul. św. Anny	20	20	ul. Lubicz	269
2	„ Basztowa	87	21	„ Łobzowska	32
3	„ Bernardyńska	70	22	„ św. Marka	15
4	„ Biskupia	16	23	„ plac Matejki	115
5	„ Bożego Ciała	14	24	„ „ Bożego Miłosierdzia	14
6	„ Dominikańska	14	25	„ Mostowa	10
7	„ Dietla	452	26	„ Poselska	30
8	„ Franciszkańska	28	27	„ Podwale	154
9	„ św. Filipa	16	28	„ Podzamcze	35
10	„ „ Gertrudy	67	29	„ Pędzichów	40
11	„ na Groblach	38	30	„ Retoryka	37
12	„ Helclów	25	31	„ Rynek główny	172
13	„ droga do parku Dr. Jordana	450	32	„ Rakowiecka	206
14	„ Kapucyńska	8	33	„ Starowiślna	124
15	„ Karmelicka	144	34	„ Stradom	38
16	„ Krowoderska	42	35	„ Słowiańska	14
17	„ Kolejowa	120	36	„ Szlak	35
18	„ Kopernika	152	37	„ Studencka	30
19	„ Krótka	16	38	„ Straszewskiego	158
39	ul. Sobieskiego	20	40	ul. Szewska	12
41	„ WW. Świętych	42	42	„ Wiślna	35
43	„ Sienna	20	44	„ Wolska	110
45	„ Strzelecka	23	46	„ Węgłowa	15
47	„ Staszyca	17	49	aleja naokoło śródmieścia	850
48	„ Smoleńska	50			

b



The study covers sites located within the boundaries of three rings:

I. the first – the Old Town, Kazimierz and Stradom – with medieval layouts;

II. the second - the ring road between Planty and Dietla Street and the circular railroad liquidated in 1911 (Trzech Wieszczów Avenue since 1912) – routes of varied origins, predominantly nineteenth- and early-twentieth-century, during the formation of the urban structure;

III. the area outside the second ring road – including nineteenth- and twentieth-century streets in the former villages of Czarna Wieś, Nowa Wieś and Półwsie Zwierzyniecke, emergent; area outside of the Greater Cracow regulation plan competition (1910).

Fig. 1. a) Green streets and squares of Cracow included in the compilation of B. Malecki [1907, pp. 9–10], with numbers added; b) plotted on a map of the Cracow Fortress (1907) with numbers and division into three rings; original work

Ryc. 1. a) Ulice i place objęte opracowaniem przez Bolesława Maleckiego [1907, s. 9–10] z dodaną numeracją; b) naniesione na mapę Twierdzy Kraków (1907) z numeracją i podziałem na trzy pierścienie; opracowanie własne

in Krakow, and in 1903 so did the first automobile, which dramatically changed the shape of the streets.

Research objectives:

- a comparative analysis of changes in greenery, primarily the number of trees, of Cracow's streets and squares from the beginning of Modernism to the present;
- analysis of factors that affect the transformation and assessment of long-term changes;
- identify opportunities to restore and introduce greenery as an important element of identity and genius loci, cohesion, biodiversity and green infrastructure;
- determine whether the city's efforts focus only on restoring historical layouts and aestheticizing spaces, or whether they consider adapting streets and squares to climate change and protecting biodiversity, in line with the priorities adopted in city documents;
- investigate whether these actions apply to individual streets and whether there is a long-term policy of tree planting for historic areas.

General overview of the literature

The subject of planning street greenery is widely discussed in the literature [Coleman et al. 2022; Global Street, 2025]. Most often, the presence of trees in urban areas is discussed in the light of their environmental values. Research has been conducted on their cooling effect, in parks [Bowler et al. 2010] and along streets [Shashua-Bar, Hoffman 2000], and as support of urban planning [Zardo et al. 2017]. The literature on improving the microclimate of cities has evaluated, among other things, the habitats and species of street trees [Jim 1992], street orientation [Sanusi et al. 2016], changes in canopy cover [Doick et al. 2020; Shiraishi, Terada 2024], and their effect on shading [Li et al. 2018]. Street trees have been observed to provide a range of ecosystem services, including environmental services such as air filtration, microclimate regulation, noise reduction, stormwater drainage, wastewater treatment and recreational services [De Groot 2002]. The effects of the distribution and density of greenery (e.g., avenue trees, green facades, rooftops) on airflow were studied [Gromke et al. 2015]. The impact of street trees on property values and the phenomenon of gentrification was analyzed [Donovan et al. 2021]. The benefits of ecosystem services in line with the UN Sustainable Development Goals, which promote tree planting and conservation, were described [Turner-Skoff, Cavender 2019].

The review of Polish literature included works on the urban development of Cracow [Purchla 1990], the history of its streets [Supranowicz 1995] and greenery. This included a catalog of the gardens of the Old Town in Cracow [*Parki i ogrody* 1997], set against contemporary studies that assess changes in these green spaces [Zachariasz et al. 2021] and their continuation for neighboring urban complexes of Kazimierz and Stradom [Zachariasz et al. 2023]. Reasons for replacing trees in historic streets [Siewniak, Bobek 2010] and alley layouts [Mazur, 2019] were considered.

Currently, many Polish cities, such as Cracow, are introducing sets of trees, shrubs, climbers and perennials for use in public spaces [Muras 2016; Bach et al. 2009] or catalogs of blue-green infrastructure, like Wrocław, among others [Szopinska et al. 2020]. However, there is a lack of studies on the use of plants in historic urban environments, which is not a simple task, as Poland has different climatic zones and subzones, as well as different cultural traditions. In addition, each project in historic zones is carried out individually, under conservation supervision.

Based on a review of the literature, research gaps were identified regarding the historical transformation of the greenery of Cracow's downtown streets and squares and the relationship between conservation and technical barriers related to climate change adaptation. This is an under-explored area of research, not only in Poland, but also around the world, which results from the sensitive historic structure and climate change, which determine specific planning and governance actions, as well as design solutions and maintenance guidelines.

Methods

Our research was conducted in a multi-faceted manner, with the application of multi-criteria analysis. Three stages of work can be distinguished, which are presented below.

The methodological problems of comparative analyses generated incomplete data concerning species, planting methods, the presence of low-lying greenery and maintenance from 1907 and up to 2003. Historical iconography was used for comparisons. We focused on numerical data (number of trees, average width and height of a street, its length, and the form the trees had been planted (row, avenue, individual trees)). As a complement, we referenced other types of greenery and the presence of lawns, plant beds, or tree pits.

Disappearance of trees from Cracow's public spaces and attempts to restore them

Since the mid-twentieth century, it was possible to observe the disappearance of trees from Cracow's streets, squares and historic public spaces. This is documented by photographs and confirmed by contemporary surveys. In the second half of the twentieth century, greenery managers engaged in various design and planning actions related to street trees, but detailed guidelines and standards were lacking [*Parki i ogrody*, 1997; Siewniak, Bobek 2010]. Among the unsuccessful measures is the introduction of, among others, southern

STAGE ONE

LITERATURE REVIEW AND ARCHIVAL QUERY

- Primary source – data from Bolesław Malecki's publication [1907] including numbers of trees and species used
- Various source materials, historical (iconography, cartography), literature, including from the resources of the National Archives, the Museum of Krakow, the National Museum, were used. The literature review was based on citation databases, including Scopus, WoS, ResarchGate, Jagiellonian Library and others. Contemporary catalogs, pattern books and design standards were analyzed.
- We referenced Cracow's municipal strategies and policies, as well as the civic budget community projects.

↓

STAGE TWO

RESEARCH ON THE CURRENT STATE OF GREENERY

- A survey of tall greenery and comparative studies were conducted, and a descriptive multiple-case study was used. Qualitative criteria were considered: (including antiquity, attractive appearance, aesthetics) and quantitative criteria (number of trees and other forms of landscaped greenery, street width and length, and presence of blue infrastructure).
- The comparative study used GIS analyses to illustrate changes in tree presence. Both original surveys and data from the MSIP Municipal Spatial Information System, the LIFE Urbangreen project [2024] and the Municipal Greenery Authority in Cracow (ZZM) were used.

↓

STAGE THREE

CONCLUSIONS – CONSERVATION GUIDELINES

- At the spatial planning scale – directional policy formulation, zoning plan provisions, climate change guidelines.
- At the urban and architectural scale – design, establishment and maintenance (including historical compatibility, aesthetics, species selection, resistance to stress, climate change and extreme weather conditions).

Fig. 2. Synoptic diagram of research methods; original work

Ryc. 2. Schemat synoptyczny metod badawczych; opracowanie własne

Fig. 3. Studencka Street in Cracow, view from Planty Park, a) state as seen in 1935, NACref. 1-U-2550-2; b) trees marked on the LIFE Urbangreen map: https://krakow.lifeurbangreen.eu/pl/green-areas/#/ (accessed 09.03.2025); c) contemporary condition, 2025, photo by A. Zachariasz

Ryc. 3. Ul. Studencka w Krakowie, widok od strony Plant, a) stan z 1935 r., NAC ref. 1-U-2550-2; b) drzewa oznaczone na mapie LIFE Urbangreen: https://krakow.lifeurbangreen.eu/pl/green-areas/#/ (dostęp: 9.03.2025); c) stan współczesny, 2025; fot. A. Zachariasz

catalpa or Golden Elmsin the 1990s, e.g., along the outer perimeter of Planty Park—św. Gertrudy Street and Westerplatte Street [Zachariasz, 2019]. The twenty-first century brought a number of academic studies that documented a deterioration in the quality of life in cities, including Cracow, influenced by climate change and the formation of heat islands, among other factors [Bokwa 2023].

These unfavorable changes are recognized by residents who vote on civic budgets, not only for parks and garden squares, but also for green streets and squares. In 2022, a project of reintroducing trees to Cracow's Main Market Square was adopted and is being implemented as of the writing of this paper (2025). The 2023 edition of the budget featured a project to green other historic squares in Cracow, including Wolnica Square and Szeroka Street (now a parking lot). This was accompanied by statements that we use trees and greenery to fight the prevailing "concretosis" which creates urban heat islands that prevent happy living.

There are also good examples in Cracow, such as the implementation of Blue-Green Infrastructure (BGI) along Krakowska and Krupnicza streets, and Zwierzyniecka and Kościuszki streets, carried out under conservation supervision. There had been fewer trees on these streets or, as on Krupnicza and Krakowska Street, there had been none. Along Krakowska Street, honey locusts, a non-historic species adapted to climate change, were planted. In the context of the existing design of Cracow's street space, an innovative project was introduced on Krupnicza Street. BGI was used and complemented with a woonerf, which is a new and pedestrian-friendly form. Tackling climate change was also accomplished through water management. Tall greenery was designed in substrates that slow down water runoff into the sewer system. Low-growing greenery was planted in pots equipped with rainwater storage tanks. Black alder, never used in street plantings, was used here, as it can withstand periodic root flooding. A total of 39 trees ('Plena' sweet cherries apart from the alders), several thousand shrubs and perennials were planted. Street furniture with greenery, historical information about the route, and car and bike parking spaces were introduced [Projekt Krupnicza, Kraków 2022]. In 2024, 36 small-leaved limes were planted on Kościuszki Street, and on Zwierzyniecka Street 26 gingko trees were planted—a species sporadically used in Cracow (it is resistant to pollution, drought and extreme temperatures, and was tested in harsh urban climates, e.g., of Tallinn, Estonia, or New York). Numerous shrubs and ornamental grasses were also planted there (including 'Farmen' hybrid yews, 'Kobold' Thunberg's barberries, dwarf cherries, shiny cotoneasters, 'Sea Foam' roses, panicled hydrangeas, true sedges and reed grasses [Ruszają nasadzenia 2024].

Materials

Our research included a review of historical (1907) and contemporary (2023) data on the presence of trees along the selected downtown streets and squares of Cracow. The research area is covered by various forms of statutory conservation stipulated in the Monument Protection and Preservation Act [2003], which also addresses scenic and archaeological matters. The 42 streets and 6 squares that we investigated represent different and distinct types in historical, spatial, functional and semantic types. The lack of detailed numerical data did not allow for comparison with other periods. Therefore, we focused on 1907 and 2023, for which such data were available.

Item no.	Street/square name; historical (1907)/ contemporary if any	Construction time Character Also marked throughout the line in color – streets extending from the Main Market Square and intersecting Planty Park – streets along Planty Park	Number of trees B. Malecki's data (1907) [pcs.]	Number of trees [pcs] (2023)	Length / Width / Building height along the street or square 2023 [m] Street classification: short < 200 m average 200–500 m long > 500 m
1	Św. Anny	Delineated during incorporation in 1257	20 along Planty Park	18 within Planty Park	200 m/ 12 m /12 m/ average
2	Basztowa	A fragment of the medieval road surrounding the city walls, in its present form of the early nineteenth century, after the removal of the walls and the establishment of the City Plantations—a public park.	87	46 excluding trees in Planty Park	735 m/20 m /20 m/ long
3	Bernardyńska	1820–30s as an avenue planted with Italian poplars	70	54	330 m/ 20 m /15 m/ average

Tab. Fragment of a table displaying Cracow's streets and squares in 1907 and 2023; based on an original survey (2023) and [Malecki 1907, Supranowicz 1995, Encyklopedia Krakowa 2023]

Tab. Fragment zestawienia liczby drzew na wybranych ulicach i placach Krakowa w 1907 i 2023 r. wraz z czasem powstania i danymi dotyczącymi wymiarów; opracowanie własne, pomiary (2023) i [Malecki 1907, Supranowicz 1995, Encyklopedia Krakowa 2023]

Fig. 4a Wielopole Street in Cracow, tending of Norway maple trees, 01.1938, NAC ref. 1-G-6678-1

Fig. 4a Wielopole Street in Cracow, tending of Norway maple trees, 01.1938, NAC ref. 1-G-6678-1

Fig. 4b. Bernardyńska Street in Cracow, view from Wawel Castle, photo by Stanisław Janikowski, 1937, ref. MHK-5808/N/4

Fig. 4b. Bernardyńska Street in Cracow, view from Wawel Castle, photo by Stanisław Janikowski, 1937, ref. MHK-5808/N/4

Fig. 4c. Avenue arranged with rows on both sides of Starowiślna Street, trees planted in tree pits, 05.1928, NAC ref. 1-U-2630

Fig. 4c. Avenue arranged with rows on both sides of Starowiślna Street, trees planted in tree pits, 05.1928, NAC ref. 1-U-2630

Fig. 4d. Starowiślna Street in Cracow in winter, on the left around the tree you can see a metal protective frame, 11.1930, NAC ref. 1-U-2632-2

Fig. 4d. Starowiślna Street in Cracow in winter, on the left around the tree you can see a metal protective frame, 11.1930, NAC ref. 1-U-2632-2

Fig. 4. Historical photographs showing Cracow's tree-lined streets

Ryc.4. Historyczne fotografie pokazujące zadrzewione ulice Krakowa

Significant roles in the history of Cracow's city greenery were played by municipal inspectors in charge of it. The first was B. Malecki, who began his career in 1879, and from whose time the data for study was sourced (1907), and his successor, A. Gauze, who was active when Cracow's regulation plans were being implemented. The ornamental trees and shrubs used to decorate Cracow's parks, garden squares and trees were from 1880, from the Dąbie municipal tree and shrubbery nursery, and in Gauze's time, from the municipality's two nurseries in Dębniki and Krowodrza. In the interwar period, trees were a distinct element of the streets' aesthetics.

The overview of the study was sequenced in relation to numerical comparative research presented in detailed tables and a synthesis of transformation trends—presented on a contemporary map, along with a diagnosis of the potential to introduce greenery into selected spaces of historic Cracow. The analyses included the following data: historical and contemporary name, the time when the street or square was created (historical names, those in 1907, and contemporary, if changed, were provided). The period of the construction of streets and squares was listed, accounting for historical context, such as Cracow's town charter (1257) or modifications linked to tearing down the city walls and building Planty Park. Afterwards, we list: the number of trees in 1907 and 2023; length; we distinguished long streets (over 500 m) – 14, medium streets (200–500 m) – 22, and short streets (less than 200 m) – 6 (excluding squares), along with each street's width and height (average) (Tab.). The second part of the table lists characteristics like: a street's/square's dominant use—historical and contemporary (attractiveness, historicity, architecture, citywide and local vistas, formality, citywide significance, me-

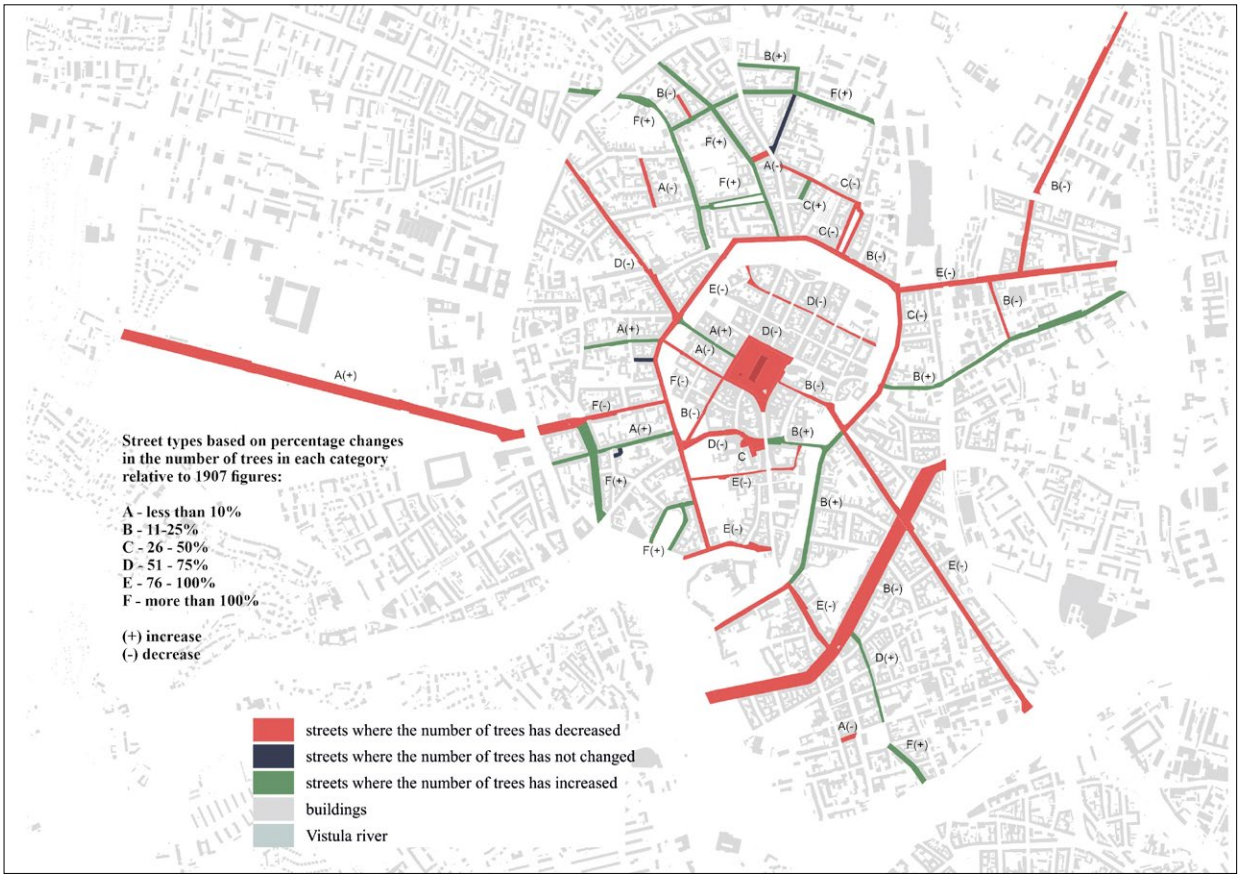


Fig. 5. Changes in the number of street and square trees covered by B. Malecki's 1907 report and in recent years (2023); source: based on original data, MSIP and ZZM.

Ryc. 5. Zmiany w liczbie drzew ulicznych i placowych – porównanie danych z raportu B. Maleckiego z 1907 r. oraz stanu obecnego (2023); źródło: dane własne, MSIP i ZZM

morial value), as well as heritage protection, potential for modification. These are the tangible and intangible data that determine identity and genius loci. We also listed the streets and squares by their formality and significance with regards to the city's image: the highest rating applied to 13 sites, the average to 27, and the low to 10.

In 1907, the number of trees in the area under study was 4509, of which 850 trees that belonged to the so-called "avenue around the center" were excluded, as its name was not found, but the name could refer to Planty Park or the avenue-ring in this park. After subtracting this avenue, **in 1907, there were 3659 trees in streets and squares investigated, while in 2023 there were 2170 trees, which is 59.3% of the original value**. **In 1907, 411 trees were recorded in the squares, and in 2023—220, which is 53.5% of the historical state.** In the Main Market square, the number of trees decreased from 172 in 1907 to 50 in 2023. Among the streets investigated, avenues numbered 10, and their number decreased to only 3. In 1907, avenues featured 2136 trees, while in 2023, the 3 surviving avenues sported 518 trees, which is only 24.3% of the original number. These statistics show that the number of trees in the area clearly decreased.

Results

Our study presents the trends in the transformation of street and square greenery. They show that major circulation routes used to have significantly more trees, as did formal spaces. The removal of trees from urban space was particularly evident along 3 Maja Avenue, Piłsudskiego, Karmelicka, Sobieskiego, św. Filipa, Lubicz, Rakowica, and Strzelecka streets, the ring road around Planty Park (Podwale, Basztowa, Westerplatte), Starowiślna, Bernardyńska, Stradomska, Węglowa, as well as Podzamcze Streets, and in the Old Town: Poselska, Franciszkańska, Wiślna, św. Anny, Sienna, św. Tomasza, and in squares: Jana Matejki and the Main Market Square. Trees on Pędzichów, Krótka and Kapucyńska streets remained unchanged in number. In contrast, the number of trees increased on Łobzowska, Krowoderska, Szlak, Helclów, Kopernika, Bożego Ciała, Mostowa, Dominikańska, św. Gertrudy, Studencka (Fig. 3), Retoryka and Smoleńsk streets, and on Biskupi and Na Groblach squares. Changes in the number of trees were a consequence of urbanization and intensive development, both in terms of transport and commerce. Despite its compact urban structure and historical origins, the area shows potential for the continuation of green streets and squares.

Street types:
a) - streets of medieval origin, narrow, without greenery;
b) - streets from the nineteenth and twentieth century, wider, with greenery on one side (e.g., Basztowa);
c) - streets from the early twentieth century, wider, with greenery on two sides, designed as avenues (e.g., Bernardyńska, Karmelicka);
d) - streets with multi-row avenue layouts from the nineteenth and the early twentieth century (3 Maja streets, Planty Dietlowskie).

Fig. 6a). Floriańska street with streetcar line, 1932, NAC ref. 1-U-2419-1

Fig. 6a). Floriańska street with streetcar line, 1932, NAC ref. 1-U-2419-1

Fig. 6b). Basztowa Street, row on one side, postcard, 1918, Sztuka, Polona, BN, DŻS XII 8b/p8/3;

Fig. 6b). Basztowa Street, row on one side, postcard, 1918, Sztuka, Polona, BN, DŻS XII 8b/p8/3;

Fig. 6 c). Karmelicka Street seen from the side of Krakowski Park, 1926, NAC ref. 1-U-2468a

Fig. 6 c). Karmelicka Street seen from the side of Krakowski Park, 1926, NAC ref. 1-U-2468a

Fig. 6 d). 3 Maja Avenue, 1934, NAC ref. 1-W-2656-5

Fig. 6 d). 3 Maja Avenue, 1934, NAC ref. 1-W-2656-5

Fig. 6. Street types identified among the investigated Cracow sites; original work

Ryc. 6. Typy ulic wyodrębnione spośród badanych obiektów w Krakowie, z przykładami; opracowanie własne

Factors that affect greenery transformation in the area

The purpose of this study was to critically examine the factors that affect the transformation of Cracow's downtown greenery. Historical iconography from different years shows that for street and square trees, apart from the outline, the conditions in which they grew, routine care and maintenance, including in winter, were key. Another factor was the fashion for certain species. The Italian poplar is a notable example, as it was widely popular in the nineteenth century and quickly disappeared from Cracow's landscape. Malecki [1907] lists the main species planted as: Norway maple, field elm, box elder, lime, chestnut in Planty Park and ash trees on 3 Maja Avenue. Changes in the number of street trees stem mainly due to the development of transport and traffic intensity. This is particularly evident in streets where tram transportation was introduced and the number of lanes increased, resulting in the widening of roadways and the narrowing of sidewalks at the expense of greenery (Dietla Street, Trzech Wieszczów Avenues, Starowiślna Street). The creation of new parking spaces and the introduction of various underground infrastructure into the spaces of sidewalks and accompanying greenery are also reasons for the disappearance of trees from the streets. These also include infrastructure repairs, during which greenery is cut down or trees are damaged, de-

Type of greenery/ planting method	Form/species/ function
Tall trees planted in green belts or tree pits, sometimes with a steel grating tree cover	Form: designed as rows, avenues and counter-alleys, used in wide streets, e.g., 3 Maja Avenue, where ash trees were planted (Malecki, 1907), with maples, among others, added later. In the streets were planted common unformed maples, small-leaved limes, common ashes, horse chestnuts (Bernardyńska Street), and black locusts. Currently, streets and squares are planted with, among others, 'Elsrijk' field maples, 'Fastigiata' common hornbeams, and silver limes. Function: Tall trees provide shade, are a natural barrier between the sidewalk and the street, and co-form the overall aesthetic. They are also often adjacent to green spaces or open areas, such as Bernardyńska Street and 3 Maja Avenue.
Medium-sized trees, planted in green belts or tree pits, sometimes with a steel grating tree cover	Form, species and maintenance: planted in rows or avenues, used in narrower, downtown streets, in less extensive spaces. Lower varieties were used, such as globular varieties, maples or locusts, Prunus eminens or molded trees. In Cracow, mainly common maples were trimmed, such as in the Main Market Square and on Wielopole Street. Function: they contribute to the aesthetics of the street, provide shade, and are a natural barrier that separates the sidewalk from the street.
Hedges, lawns, flowerbeds, planted in pits or green strips, sometimes with a low fence	Form: hedges were planted along sidewalks and at plot boundaries. Similarly, lawns and beds of ground cover plants, perennials or low shrubs. Used, for example, on Pędzichów Street. Privet, boxwood and common hornbeam were planted, with euonymus popular today. Function: to bring colored patches into the cityscape, enhance aesthetics and biodiversity. They serve decorative functions and as a protective barrier against road pollution. Green strips (pits or strips) along streets help absorb rainwater. They mitigate the impact of paved infrastructure.
Vines planted in pits or green strips	Form: vines are also used on supports (special structures, sometimes stylized), located along streets or next to buildings. Used on supports, for example, on Lubicz Street and Piłsudskiego Street (trumpet vine). Vines such as ivy or climbing hydrangea can be used as bedding plants in pits or green strips. Function: vines on a frame can provide a natural barrier separating the sidewalk from the street, improve its aesthetics, and help cool the air on hot days.

Fig. 7. Types of greenery, forms and functions of street greenery in central Cracow; original work

Ryc. 7. Rodzaje zieleni, formy i funkcje zieleni przyulicznej w śródmieściu Krakowa; opracowanie własne

stroying their root systems, disrupting their statics, and ultimately leading to the tree's removal. Sometimes, changes in greenery result from modifications to the use structure of neighboring developments, including the creation of café terraces. Prolonged droughts, waves and torrential rains are just some of the global phenomena related to climate change that negatively impact urban greenery. Consequently, many trees are deteriorating because the species chosen are not suited to large temperature fluctuations (especially in summer) or other sudden weather events. However, a positive change can be seen in grass-roots initiatives, civic budgets dedicated to parks, and garden squares, as well as the greening of streets and squares.

Figure 6 shows four types of streets divided by tree presence of absence. The routes were analyzed in terms of tree presence. Street trees ordered into rows, avenues or counter-alleys (more than two rows and more than two traffic lanes) are shown.

Another division relates to the susceptibility to changes in the number of trees resulting from transportation, which has a major impact on plant reduction. The following were identified:

- primary transportation routes, most susceptible to tree number reduction,
- side streets with less traffic, here parking lot projects are a threat;
- streets/avenues along which, apart from carriageways, there is also a strolling path, atypical layouts, quite persistent, 3 Maja Avenue and Bernardyńska Street.

Among the squares analyzed, there are spaces that are significant for the image of the city, that are formal, including the vast Main Market Square and the squares: Matejki and Wszystkich Świętych, as well as less prominent squares: Bożego Miłosierdzia (today a street) or Na Groblach and Biskupi. For these spaces, there is a positive movement to restore trees, such as on św. Ducha Square.

Street greenery in Cracow can be divided into several categories (tall trees, medium-sized trees, hedges, lawns, climbers, flowerbeds), depending on height and the way it is shaped (row, avenue, solitary forms). Aesthetic qualities are also important—outline, color, blooming, fruit. Historically used species were also typical (Fig. 7), recently replaced by more resistant species and varieties.

Based on a multi-criteria analysis, the potential of individual streets and squares was assessed, considering a number of constraints and potentials. The analy-

sis considered, among others, the time of construction and age of the sites, their historic character, including forms of statutory conservation, and location in archaeological zones. The sites' formality, citywide significance, attractiveness, identity and other features, such as memorial value that builds genius loci, were all major criteria. The assessment also took into account the attractiveness of vistas: openings, sequences, and visual linkages, both at the city scale and in the local context, of neighborhoods. As for the technical parameters of the streets, the length, width and average height of the frontage were evaluated, among others, which affect the shading of the space (Table 1).

Street greenery development policy and impact of statutory conservation type

Municipal documents show that there is a lack of general directional guidelines for designing Cracow's squares and streets, both historical and contemporary, with greenery or BGI. The ZZM conducts a policy concerning managing Cracow's greenery system and the ongoing surveying of the city's trees [LIFE Urbangreen, 2024, Fig. 3]. There are guidelines in terms of location-suitable species, but for historic sites, every street and square should be approached on a case-by-case basis. Statutory conservation forms that protect streets and squares are the basis for conservation approvals and listing a site in the register of monuments or inclusion in an area-based listing, a cultural park (for which a conservation plan and suitable provisions are prepared), a monument to history, and zoning plan provisions concerning both conservation and planning, including obligatory biologically vital area ratios [Zachariasz et. al 2023]. Two types of visual aspects are key in introducing greenery—vista conservation and attractiveness in scenic routes or openings, crucial to the genius loci. The wide-ranging discussions among specialists and residents on greenery in historic streets and squares illustrate just how difficult it is to introduce greenery. Sometimes, in the absence of historical evidence, the presence of unexplored archaeological zones, the threat of obscuring views and too many utility lines, planting trees is impossible or severely limited.

However, there is a large group of sites where it is possible to consider planting trees (even when there were none before, as the projects listed show), or additions in rows. It is also possible to use other forms of greenery used in Cracow, climbing plants on facades (here it is necessary to cooperate with tenement owners and the conservator), climbing plants on racks, ground cover plants along the streets, green tram tracks (they are on 3 Maja Avenue). In terms of green infrastructure, yards and small areas of greenery in the form of lawns adjacent to a street offer greater opportunities for such solutions. This is a good location, for example, for forms such as bioswales, bioretention planters or biofiltration planters. The introduction of permeable paving in parts of the sidewalks could also be considered. It can serve street furniture (e.g., public transportation stops, kiosks) and can be supplemented with green walls, roofs, and water tanks. We analyzed which green infrastructure elements could be implemented in the areas and initially identified their application potential. We rated the potential for BGI introduction and found 35 streets suitable for it to support sustainability and excluded primarily streets from the town charter issue period. Management and responsibility for planting and maintaining street greenery is a separate issue.

Discussion

Assessing the current site development and comparing 2023 greenery with the historic state (1907) was an essential aspect of this study and allowed us to determine percentage-based changes in plant cover. We focused on analyzing the factors that contributed to these changes. Trees were treated as a key element of urban design and street structure, which have important functions: they delineate the pedestrian zone, build visual order, benefit the landscape by introducing beauty in the form of nature, but also calm traffic. Transformation of the green structure in urban interiors is aimed at improving the quality of life of residents by adapting spaces to contemporary needs. We assumed that streets fulfil various functions to satisfy essential human needs in terms of habitation, work and transportation, but, depending on space type, strolling, recreational and environmental functions are added.

Squares and streets are an important element of urban space, so modernizations should be carried out with great care, ensuring the unique historical values and identity of these places is preserved [Szmygin 2024]. It is important to respect the unique character of the place and to integrate the greenery with the historic urban development, thus preserving cultural values.

Our research shows the dependencies between functional transformation across the years and the change in tree numbers. They also point to the urgent need to develop detailed greenery policies in the city, particularly in historic areas. It is recommended to act on several levels: spatial planning, design, and the establishment and ongoing maintenance of greenery, which will enable harmonious urban landscaping in the historic structure.

It is recommended, at the level of:

- **Spatial planning**

It is essential to continue to include greenery as a key element of spatial policy in order to make cities more resilient to climate change and improve the quality of life for residents. Green streets enrich the structure of urban green spaces. This requires a broader perspective at the national level and effective implementation in local planning documents. Protecting and shaping greenery in historic spaces needs an integrated approach, combin-

Measures aimed at increasing the number of trees in city centers should address several levels: planning, design, establishment and ongoing maintenance, which translates into three stages:

I) pre-design – analysis, policymaking and planning,

II) design and execution – establishment,

III) management and use, ongoing care, maintenance, monitoring. These measures should be part of the city's climate change adaptation plan.

PREPARING THE GREEN STREETS PROGRAM AND ENSURING ITS OPERATION

Assessment and diagnosis in terms of greening different types of streets, the need to build a program. The key is to prepare catalog of streets divided into major groups, with a survey, condition assessment (including species, their stability) and conservation guidelines (developed in cooperation with the conservator municipal city road manager).

Preparing standards for planning, design and programs.

Identification of conflicts, existing and potential – ecological, planning, design and social conflicts that may arise from projects.

Economic estimates of the benefits of creating a green space structure.

Monitoring – environmental, ecological (including species stability), economic, social, survey studies on the operation of the system and the functioning and use of each street type.

Fig. 8. Diagram of the creation and operation of a system of green streets of Cracow for areas under statutory conservation
Ryc. 8. Schemat tworzenia i funkcjonowania systemu zielonych ulic Krakowa dla terenów objętych ochroną konserwatorską

ing spatial and conservation policies. It is crucial to consider both cultural values and contemporary user needs, and to integrate planning goals with climate challenges at different levels. It is also essential to consider the hierarchy of users in revaluation processes, with priority given to pedestrians in selected spaces. Spatial planning should gain more flexibility, for instance by designating climate action zones that foster interdisciplinary cooperation and the implementation of adaptation strategies, as well as by limiting certain forms of development and applying new technologies. In addition, attention is paid to providing access to green spaces to protect against heat [*Prawo planowania*, 2024].

Planning instruments can support both climate change adaptation and mitigation efforts. This requires not only protecting existing greenery, but also its active shaping, i.e., by including rows of trees and other forms of street greenery in local development plans to protect against heat. While this is partially being implemented, there is still a lack of comprehensive regulations for areas of historical value. It is worth considering provisions in local plans that allow a minimum proportion of biologically vital areas for streets. For squares (publicly accessible ones with an area of more than 1,000 m^2) there is a legal regulation that at least 20% of their area should be a biologically vital area, unless there is another recommendation of the local plan [Warunki, 2022].

It is good practice to introduce new spatial planning documents, such as landscape or greenery plans (e.g., Berlin's Landschaftsplan), especially in densely built-up central areas. These documents focus on protecting the biologically vital area inside city blocks and, in the case of renovations and modernizations, increasing it in accordance with the adopted urban standards for a given use and block [Kochel 2023].

- **Design, establishment and ongoing maintenance**

General principles for the design, selection, and shaping of green areas, that consider the specificity and compatibility of the geographical, climatic and cultural characteristics of Cracow were presented by P. Muras (2016). Muras noted the need for conservation authority approval in terms of species and variety selection, which is also affected by climate change. Species compatibility, including historical compatibility, is important. At present, varieties more resistant to changing climate conditions and new BGI-related technologies are more often considered, as well as those that are better suited to urban needs, similar in outline but, for example, lower, less opaque or narrowly columnar, that tolerate cutting or are competitively more resilient than others, as described above. For streets and squares, species that have high resistance to drought, low humidity, and dust and gas pollution, especially concentrations of exhaust fumes, are desirable. Where brine is used, it is advisable to adjust vegetation or protect it (currently, soil is protected with mats). Species with brittle, easily broken branches and those that litter and soil pave-

ments are also not recommended in road lanes. It is indispensable to monitor the sites and perform ongoing maintenance.

The research indicates an urgent need for detailed recommendations for trees on streets and squares in the context of the historic urban fabric. We proposed a diagram for measures linked to creating a green street program.

Conclusions

Data on the number of trees in Cracow's streets and squares from 1907 was compared with the results of contemporary measurements (2023). Although the results generally showed a decrease in the number of trees by 1,489, of which 191 were trees from squares, there were cases of growth and retention. Nearly 60% of the decrease was due to transformations within the streets associated with, among other things, the construction of technical infrastructure or changes in development. There was a decrease in the number of trees on 33 streets, while 14 saw an increase and 3 remained unchanged (Fig. 5). We found that, even today, layout structure and morphology based on historical planning have an essential impact on street development. Street width and building height are two key determinants. The third is the changing function of a street, with an emphasis on different types of transportation: pedestrian, vehicular, rail and parking needs. Pavement changes and the amount and type of infrastructure, the potential for an underground infrastructure main duct, and the risks to heritage values in case of interference and the cost of the project estimated economically, are all important.

The layouts of Cracow's medieval streets, for the most part, with a grid-like layout dating back to 1257, are almost impossible to develop with greenery due to the fact that they are too narrow. Deviations occur in wider, atypical streets, such as Poselska Street by the City Hall or streets with bifurcations (św. Marka, Reformacka, Kanonicza and Podzamcze), when connecting a pre-charter structure with a new one (Wszystkich Świętych Square), or fringe layouts with Planty Park, formerly the city walls (Olszewskiego Street).

Squares also have the potential for greenery introduction, as proven by relying on calculations [Zachariasz et al. 2023], where Old Town squares, such as Szczepański and św. Ducha, were identified as those where green space and the number of trees increased. This is also confirmed by recent studies conducted on the Main Market Square and the decision in 2025 to plant more than 20 new trees.

The area under study is incredibly sensitive, and its heritage character is crucial. Street design proposals require conservatorial approval, as well as coherent renovation policy, which assumes the establishment of shared main utility ducts, which may prevent the greening of the outer parts of carriageways. However, due to the presence of historic cultural layers beneath the pavement, most activities should be carried out with archaeological supervision and with good prior historical reconnaissance. Streets and squares, as public spaces accessible to all, are subject to social assessment, as evidenced by Cracow's civic budget projects and implementations. Experience with the introduction of greenery in the streets: Krupnicza, Krakowska and Zwierzyniecka also shows that the variant of developing the route with greenery is also acceptable where there was none before. It is possible to introduce species historically not used, better able to withstand urban conditions and more resistant to climate change, and it is possible to obtain conservatorial approval.

The above research confirms that there is still a lot of potential for introducing greenery to Cracow's streets.

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Abstract

The restoration and introduction of trees into city centers are currently major challenges in heritage conservation. Changes in land use have led to a significant reduction in tree numbers, which blurs the identity of traditional cultural landscapes and increases the nuisance associated with climate change. This paper investigates the impact of urbanization on the number of trees in central Cracow. A comparison was made between their number on 42 streets and 6 squares, as documented in 1907 and 2023. The historic spaces covered by this study display high historical and urban diversity. Literature studies, historical source queries, tree surveys, and multi-criteria analysis using GIS were conducted. We found a general decrease in the number of trees, and few cases where this number increased or stayed the same. The trends observed were caused by the development of transport, technical infrastructure, and stress accumulation. We formulated conservation, planning and environmental guidelines and identified potential for restoring trees and listed their benefits and good practices.

Streszczenie

Przywracanie drzew w centrach miast i wprowadzanie ich do centrum to ważne zadanie konserwatorskie. Zmiany sposobu użytkowania przestrzeni doprowadziły do znacznej redukcji drzew, co zaciera tożsamość tradycyjnych krajobrazów kulturowych i zwiększa uciążliwości związane ze zmianami klimatu. Celem pracy jest zbadanie wpływu urbanizacji na liczbę drzew w centrum Krakowa. Porównano ich liczbę na 42 ulicach i 6 placach w 1907 i w 2023 r. Badane zabytkowe przestrzenie cechuje duża różnorodność historyczna i urbanistyczna. Przeprowadzono studia literatury, kwerendy źródeł historycznych, inwentaryzację drzew i analizę wielokryterialną z użyciem GIS. Wyniki wykazały zmniejszenie liczby drzew, nieliczne są przypadki wzrostu lub utrzymania ich liczby. Trendy wynikają z rozbudowy transportu, infrastruktury technicznej oraz kumulacji wyzwań środowiskowych. Sformułowano zalecenia konserwatorskie, planistyczne, środowiskowe i wskazano możliwości przywrócenia drzew, płynące z nich korzyści i związane z nimi dobre praktyki.