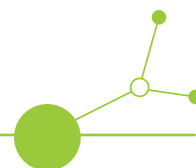


RE-PUBLIC SPACES

D1.2.1. STRATEGY FOR ADAPTING FIVE HISTORIC COURTYARDS TO CLIMATE CHANGE IN THE CITY OF OSIJEK



Version 1

Energy Institute Hrvoje Požar peer
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1. Characteristics of the urban complex

1.1. Historical background of Osijek

City of Osijek is characterized with a rich historical and cultural heritage. Osijek has been continuously inhabited for nearly two thousand years, with its urban organization and structure largely based on designs established shortly after the departure of the Ottomans, in the late 17th and early 18th centuries. Since then, the city has grown and evolved around this foundational layout. The city's significant development occurred during the Baroque, Classicism, and Art Nouveau periods, evidenced by numerous cultural and historical monuments from those eras. Within the city, 3 historic urban cores (complexes) are present - Tvrđa ("The Fortress"), Gornji Grad ("Upper Town") and Donji Grad ("Lower Town").

According to the definition provided by the Ministry of Culture, the historical complexes of a city are unique clusters of buildings that hold significant historical, archaeological, artistic, and social value, interconnected enough to form distinct spatial characteristics. The Cultural and Historical Complex of the City of Osijek is registered as a protected immovable cultural asset.

One of the most significant and recognizable historic and cultural aspects of the city is Tvrđa. This area includes a well-preserved urban core, sections of the bastion toward the Drava River, the partially preserved but dilapidated Crown Fortress on the left bank of the Drava, and a park area on the site of demolished fortifications. It represents a heritage site of immense historical and cultural importance. Tvrđa represents the central historical core of the city and it is a distinctive example of the typologically specific urban form of an 18th-century Baroque fortress-city. It emerged through a dramatic Baroque transformation of an older historical settlement. What sets Tvrđa apart from other Baroque cities is its seamless blend of military fortifications and an orderly urban layout that supports both civil life and spiritual activities. Within Tvrđa, there are fourteen structures of secular architectural heritage and two sacral buildings, all listed in the Register of Cultural Assets maintained by the Ministry of Culture. These assets highlight



the rich historical layers and architectural significance of Tvrđa, underscoring its importance as a cultural and historical treasure within Osijek's urban landscape [32].

During the construction of Tvrđa for military and strategic purposes, the population residing on the periphery of the fortress was relocated south, east, and west of Tvrđa. To the west, Gornji Grad ("Upper Town") emerged. This part of the city was developed systematically and with an organized urban structure. Over time, Gornji Grad became the central hub of Osijek, and with rapid economic development at the turn of the 19th and 20th centuries, new streets were constructed at an impressive pace. This expansion led to the creation of some of the city's most beautiful and representative areas, characterized by its squares, thoughtfully planned streets, and outstanding examples of architectural design [32].

Gornji Grad is particularly noted for its Art Nouveau (Secessionist) architectural heritage. A significant highlight in this regard is European Avenue, a majestic boulevard adorned with opulent Art Nouveau palaces that were constructed for Osijek's industrialists and distinguished citizens in the early 20th century. Among the most original achievements of this architectural style is the Urania Cinema, designed by architect Viktor Axmann in 1912, alongside the Main Post Office building, also completed the same year. European Avenue currently boasts the longest stretch of Art Nouveau architecture in Southeast Europe [32]. It is a residential stretch of single-story and two-story urban buildings with front gardens. According to the Register of Cultural Goods, twelve buildings located on European Avenue are listed as protected cultural heritage. Gornji Grad holds the highest number of immovable cultural assets of both secular and religious architectural heritage, along with two archaeological heritage sites, all registered in the Register of Cultural Goods maintained by the Ministry of Culture.

1.2. Selected historical districts

The courtyards within Tvrđa have been strategically chosen for revitalisation through green and blue infrastructure due to their exceptional historical and cultural significance, as well as their current urban challenges. Tvrđa, being the central and most distinguished historical core of Osijek, embodies the city's rich Baroque heritage and typifies the unique



blend of military and civil urban planning. However, the area is also characterised by a high proportion of impermeable surfaces, that only exacerbates urban heat island (further UHI). In historic cities due to the historic urban planning and current climatic conditions as well as dense urbanization and limited green space UHI is even more prominent [11]. Limited number of studies highlight that historical urban centres, due to being highly stratified and dense, are the most vulnerable places to ongoing climate change [21].

As establishing resilient and health-conscious urban landscapes is becoming an imperative to shield communities from escalating health risks exacerbated by the UHI effect [39], historic cities are increasingly recognizing the significance of adopting adaptation strategies to maintain liveable conditions. Therefore, by focusing revitalisation efforts on the selected courtyards within Tvrđa, the strategy will not only enhance the climate resilience and aesthetic appeal of Tvrđa, but also to support its transformation into a vibrant cultural centre, in line with the city's broader development goals. The integration of green and blue infrastructure will help address stormwater management, UHI effect, improve microclimate conditions, and foster social interaction, thereby supporting the revitalization of the old part of the town as emphasized with Green and blue strategy of Osijek (further GBI Strategy). The location of 3 selected courtyards with the Tvrđa are shown in the figure below (Figure 1).

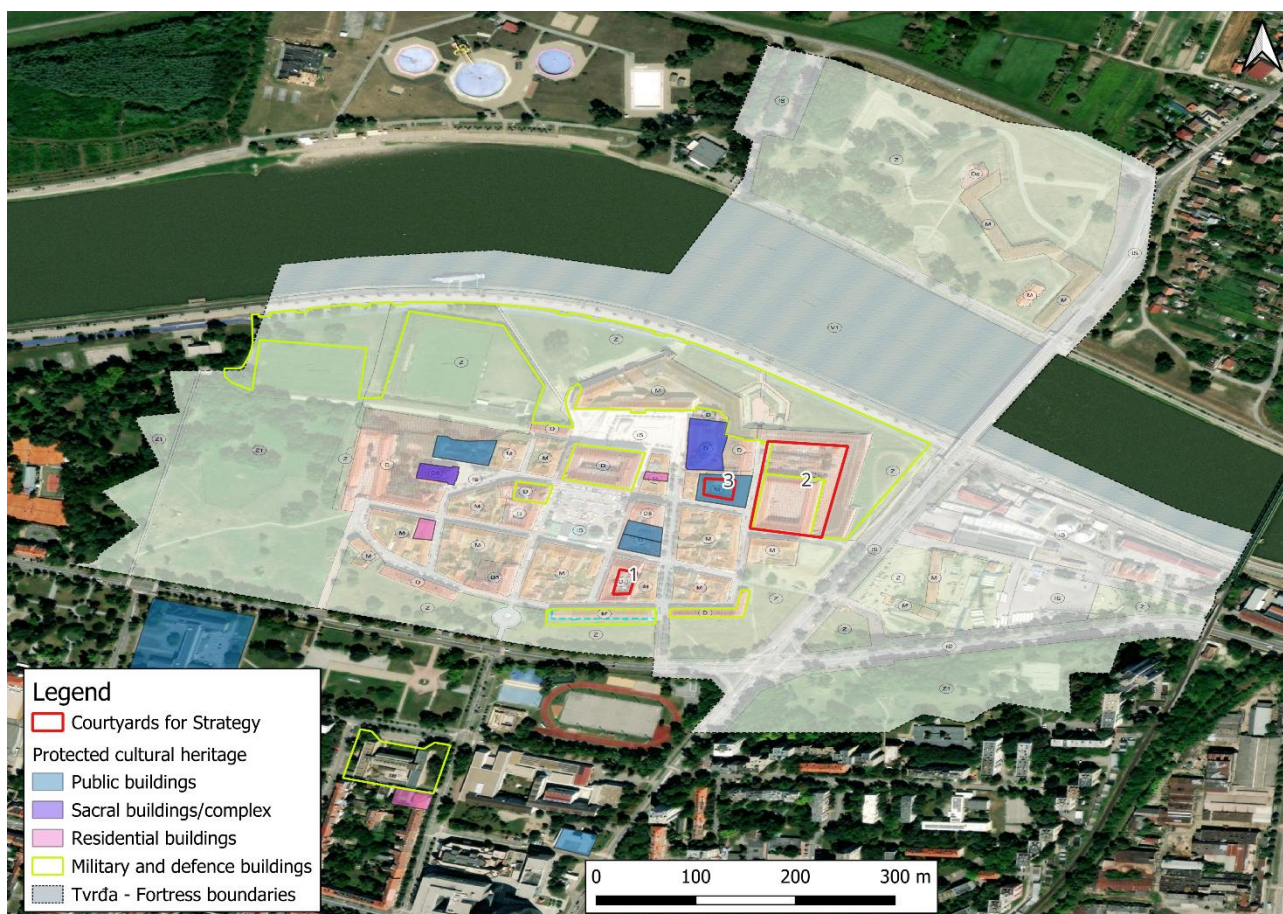


Figure 1 Tvrđa boundaries and strategy courtyards

On the other hand, the courtyards selected as pilots within this project are located within the Gornji Grad area and are closely linked to its distinctive architectural and cultural heritage, particularly the residential Art Nouveau buildings on European Avenue and the iconic Urania Cinema. Many of these buildings are protected as cultural heritage sites, making this area a vital part of the city's identity.

Given the growing challenges posed by climate change - including a documented and persistent rise in average annual temperatures and increasingly severe thermal discomfort experienced in Osijek in recent years (in the period from 2015 to 2024, all years except 2020 were classified as extremely warm), the revitalisation of these courtyards will provide a larger, interconnected green space.

Revitalizing selected pilot courtyards ensures that not only historic significance of the area is preserved, but will also deliver environmental and social benefits. By transforming these pilot courtyards, new functional and attractive spaces that improve residents'



quality of life, enhance microclimate conditions, and contribute to the mitigation of the urban heat island effect will be created. Furthermore, revitalization of pilot courtyards will foster integration of public and private heritage spaces into a unified, cohesive cultural and urban landscape, linking the historic urban fabric with the green corridors along the Drava River. This approach will deliver a resilient, interconnected landscape that both preserves historic legacy and provides the community with a healthier, more liveable environment in the face of ongoing climate pressures. The location of pilot courtyards within European Avenue is presented in Figure 2.



Figure 2 Location of pilot courtyards in regard to Urania Cinema and Art Nouveau buildings on the European Avenue

1.3. Characteristics of the Courtyards

The courtyards are located within two distinctive zones - Tvrđa core and Gornji Grad and thus due to their position and historic characterisations of the area, present different



designs. Courtyards within Tvrđa reflect a compact, military-urban typology with remarkable Baroque architecture while the area with pilot courtyards reflects the Secessionist style (Art Nouveau) and is influenced by Secession houses with rich decorations along the European Avenue and Urania Cinema, a monumental Secessionist building in Osijek.

All of the courtyards are located within the protected cultural heritage areas. Any adaptation measures must respect architectural integrity and historical character of the courtyards. Reversible and non-invasive solutions are preferred to ensure compliance with conservation guidelines.

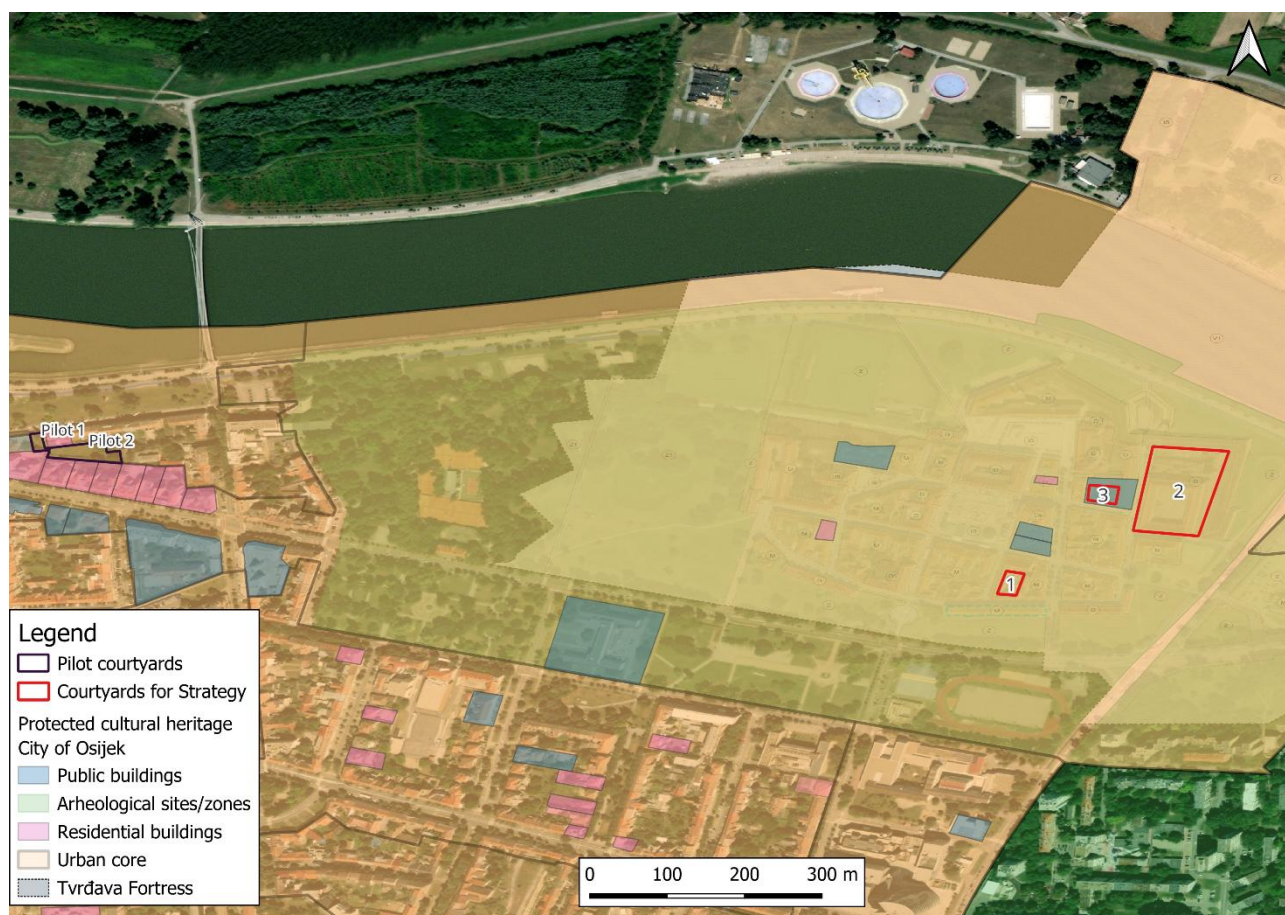


Figure 3 Location of all courtyards in relation of protected cultural heritage

Courtyards No. 1, No. 2, and No. 3 are in the historic core of Osijek, specifically the Tvrđa Fortress, and primarily feature Baroque architecture. These courtyards are spatially defined by surrounding buildings that form closed or semi-closed blocks. Courtyards No.1 No.3 exhibit a rectangular configuration with open central areas and courtyard No. 2 has



a more intricate design, with outer walls forming part of the Tvrđa constructed of red brick (Figure 4). The courtyards within the Tvrđa clearly express a military-administrative function, evident through their entrances - arched stone-framed gates with robust wooden doors (e.g. courtyards No. 1 and No. 3). Courtyards vary in size from 570 m² (courtyard No. 1) to 4692,8 m² (courtyard No. 2).

Pilot courtyards are located between residential buildings on the south and existing larger green areas on the north - northeast part, influencing their shape. They feature a more open and residential layout. Pilot courtyards are mutually connected (Figure 4). Both are situated in protected area classified as cultural and historical entity of the city and are surrounded by other protected cultural heritage. Currently, they are without a use and are closed to the public.

Courtyards within Tvrđa have more of preserved historic elements, such as arched stone-framed gates with robust wooden doors (e.g. courtyards No. 1 and No. 3), traditional lantern-shaped lamps (most often present at the entrance doors). Courtyard No. 2 possesses the most preserved historical elements such as original brick paving, iron-barred window shutters and traditional lantern-shaped lamps partly preserved within the courtyard. Pilot courtyards lack specific historic elements. Despite the locations in historically significant areas, current states of courtyards do not reflect this value or enhance the city's identity.

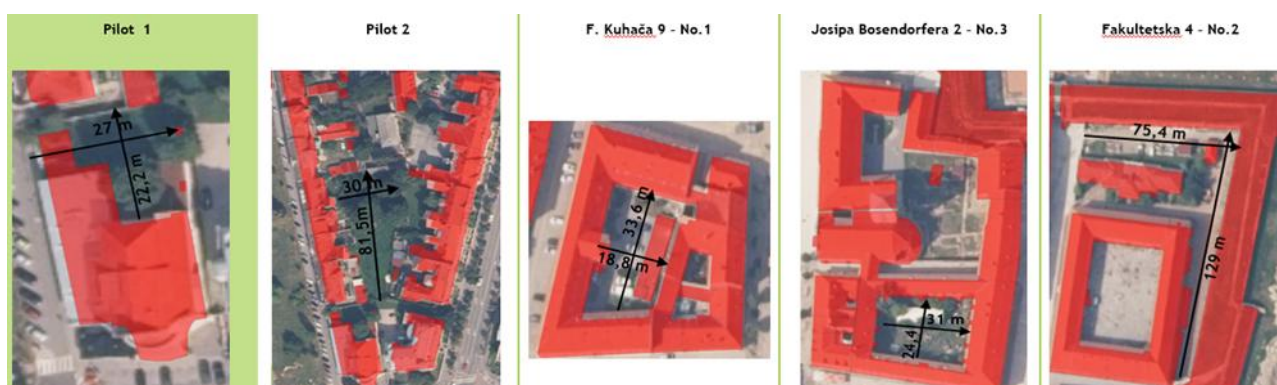


Figure 4 Inventory of the Analyzed Courtyards by Size and Shape, Source: Charter on Cortyards

All of the selected courtyards are publicly owned. This, along open access to the public ensures the successful integration of the revitalized courtyards into the urban green



infrastructure network of the city. Public ownership simplifies legal and administrative processes, allowing the city to ensure long-term maintenance and diversity of use, without the complexities of private property negotiations. This also aligns with broader strategic goals for urban environments that prioritize the preservation and expansion of communal green spaces. The courtyards planned for revitalization in city of Osijek are currently not in active use or are not used or are used for non-public purposes. Some of them are used by different public bodies as they are located within public buildings. Courtyard No. 1 is used only by employees of the City Hall and partly serves as a parking area while, courtyard No. 3 functions as a storage space for the Museum of Slavonia. Both courtyards are inaccessible, underused and without proper public function. Courtyard No. 2, unlike previously mentioned courtyards has multiple entry points and is accessible to the public. Occasionally activities such as food and wine festivals and art-related are hosted.

1.4. Accessibility

The selected courtyards (both pilot courtyards and those located in core of Tvrđa) are inaccessible to public due to locked gates and lack of function. Public accessibility is limited or non-existent in many cases, with some requiring permission (e.g. courtyard of city hall - No. 1) or being closed entirely. However, after the revitalization, it is essential that they be open to public. Public courtyards with strategically planned GBI act as focal points for residents in terms of cooling, managing stormwater, and fostering biodiversity. Moreover, they create inviting spaces for community engagement and recreation, which are integral to the principles of green infrastructure. In cases where courtyards are surrounded by residential buildings, a semi-public approach can be applied to balance accessibility with resident privacy.

Accessibility for people with disabilities is generally poor, with different obstructions present. Surfaces are often poorly maintained, with issues like uneven terrain, overgrown vegetation, and degraded paving. Both the pilot courtyards and courtyards located within the Tvrđa are not accessible for persons with disabilities due to a combination of uneven surfaces, natural soils and grass, damaged clay pavings, and lack of proper infrastructure. In several cases, steps or metal barriers obstruct entry, and ramp for people with disabilities is present only in courtyard No.1. Only in this courtyard (courtyard No.1.) the surface is relatively even, although repair work is needed due to visible damage to make



it appropriate for people with disabilities. The pilot courtyards have access paths that are mostly made of soil and grass, with no paved walkways or access ramps. The surfaces are uneven and at different levels, with one of the entrances (Pilot 1) having three steps and no alternative route for people with reduced mobility. In the second courtyard (No.2), certain areas are accessible, such as the main entrance that can be used by people with disabilities as there is no threshold, but the southern entrance has stairs. Clay brick paving poses a problem, as some areas are uneven, and several bricks are missing. The third courtyard (No.3) features a metal barrier at the entrance from the door, and the surfaces are not maintained - the clay paving tiles are completely covered with soil and grass. Uneven areas and holes are present throughout the courtyard. Through the revitalization, courtyards should be adapted to ensure accessibility for persons with disabilities and those with mobility impairments. All planned interventions should be carried out with special attention to the preservation of historical and ambient elements, using materials and design solutions that respect the cultural and historical character of the site.

2. Urban and Climate Context

2.1. Climate Characteristics and Adaptation Potential

The City of Osijek, like much of continental Croatia, falls under a moderately warm and rainy climate (Cfbwx type according to the Köppen classification). Based on data from the Croatian Meteorological and Hydrological Service for the period 2000-2024, the average annual air temperature in Osijek was 12.3 °C, with average minimum and maximum annual temperatures of 7.2 °C and 17.8 °C respectively. February recorded the lowest temperature (-25.1 °C in 2012), while August saw the highest (40.1 °C, also in 2012). The highest average maximum temperatures were observed in July and August, reaching 40.3 °C. According to the City of Osijek's Climate Change Mitigation, Adaptation and Ozone Layer Protection Programme Report [1], there has been a gradual increase in average annual temperature of approximately 1.55 °C over the observed period. In addition, when looking at percentile distribution of thermal conditions, from 2015 to 2024, all years except 2020 were classified as extremely warm, except for 2020 that was categorised as very warm.



Additionally, observed meteorological data in the same period (2000-2024) indicates that annual precipitation varied significantly, ranging from 317 mm (2000) to 1038.2 mm (2010), with an average of 687.5 mm. September was the wettest month (average 1612.3 mm), while February and March were the driest (average 41-43 mm). Summer recorded the highest seasonal precipitation (210 mm) and winter the lowest (140 mm). Snowfall predominantly occurred in winter, with an average annual accumulation of up to 160.3 cm and with January having the highest average snowfall (62 cm). However, a significant decline in snowfall has been observed since 2018 - from 235 cm that year to just 24 cm in 2023 and 30 cm in 2024. Overall, the trend indicates a reduction in annual snowfall, averaging 150 cm over the past 24 years.

Additionally, Osijek has experienced an increase in extreme weather events, such as thunderstorms and intense rainfall, which pose growing risks to infrastructure and public safety.

The Croatian Climate Change Adaptation Strategy until 2040 with an outlook to 2070 provides projections for climate change for Croatia for two future periods: 2011-2040 and 2041-2070. These projections are based on regional climate model simulations (RegCM) at spatial resolutions of 50 km and 12.5 km. For modelling, two IPCC scenarios were used:

RCP4.5: A moderate scenario with greenhouse gas concentrations peaking around 2040, assuming mitigation and adaptation measures.

RCP8.5: A high-emission scenario with concentrations tripling by 2100, considered more extreme.

The RCP4.5 scenario is deemed statistically more probable and is the primary basis for strategic planning.

Despite limitations in the simulations, they clearly signal climate change impacts in the future.

Temperature increases are projected across the region, with higher magnitudes under RCP8.5. In the near future, changes may reach up to 1.4 °C, and up to 1.9 °C in summer under RCP8.5. In the distant future, RCP4.5 projects increases of 1.9 °C in winter and spring, 2.5 °C in summer, and 1.4 °C in autumn. Under RCP8.5, all seasonal changes



exceed 2.5 °C compared to the reference period (1970-2005). In the picture below, expected changes in temperature increases are presented for Osječko-baranjska county.

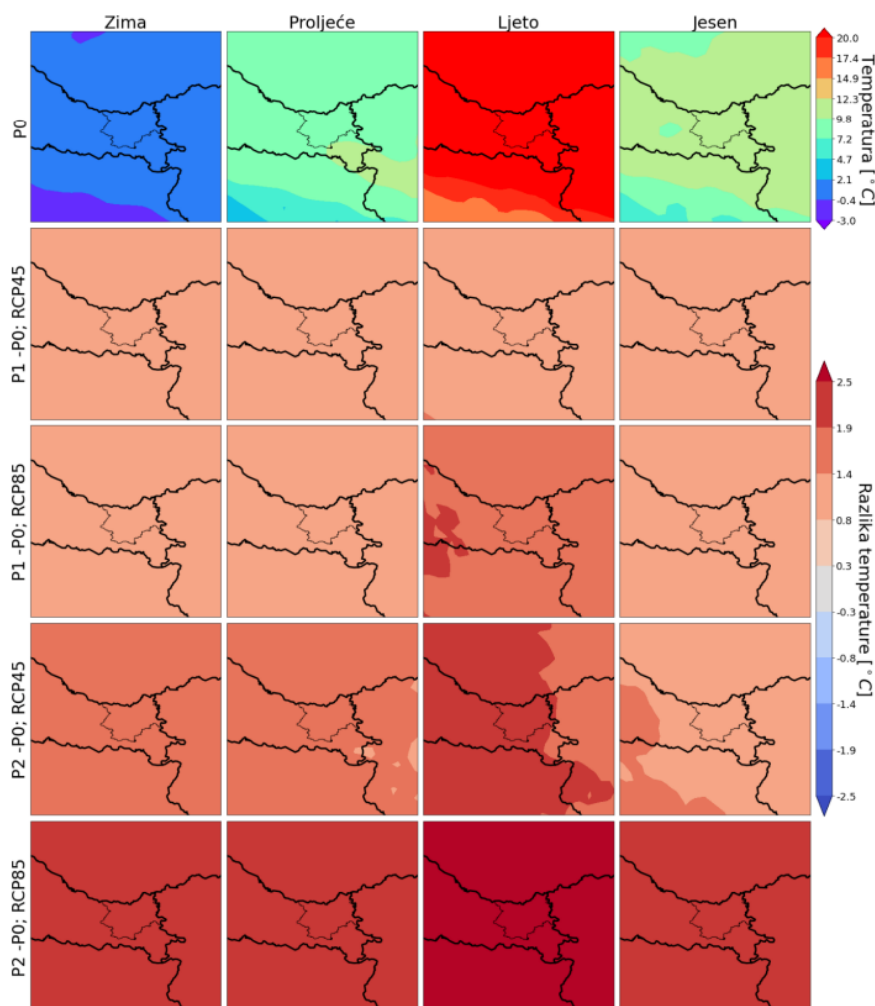


Figure 5 Median change in temperature (°C) for Osječko - baranjska county based on different RegCM models, P0 - reference period (1971.-2000.), P1 - change in period 2011.-2040., P2 - change in period 2041.-2070., left to the right - winter, spring, summer, autumn [1]

Precipitation projections show increases in winter and spring and decreases in summer under RCP4.5. Autumn trends vary by region. These trends align with observed patterns from 2000 to 2024. Both scenarios suggest increased precipitation in winter, spring, and autumn in the distant future, with summer showing a decline. In the picture below, median change in precipitation (mm) for Osječko - baranjska county is presented.

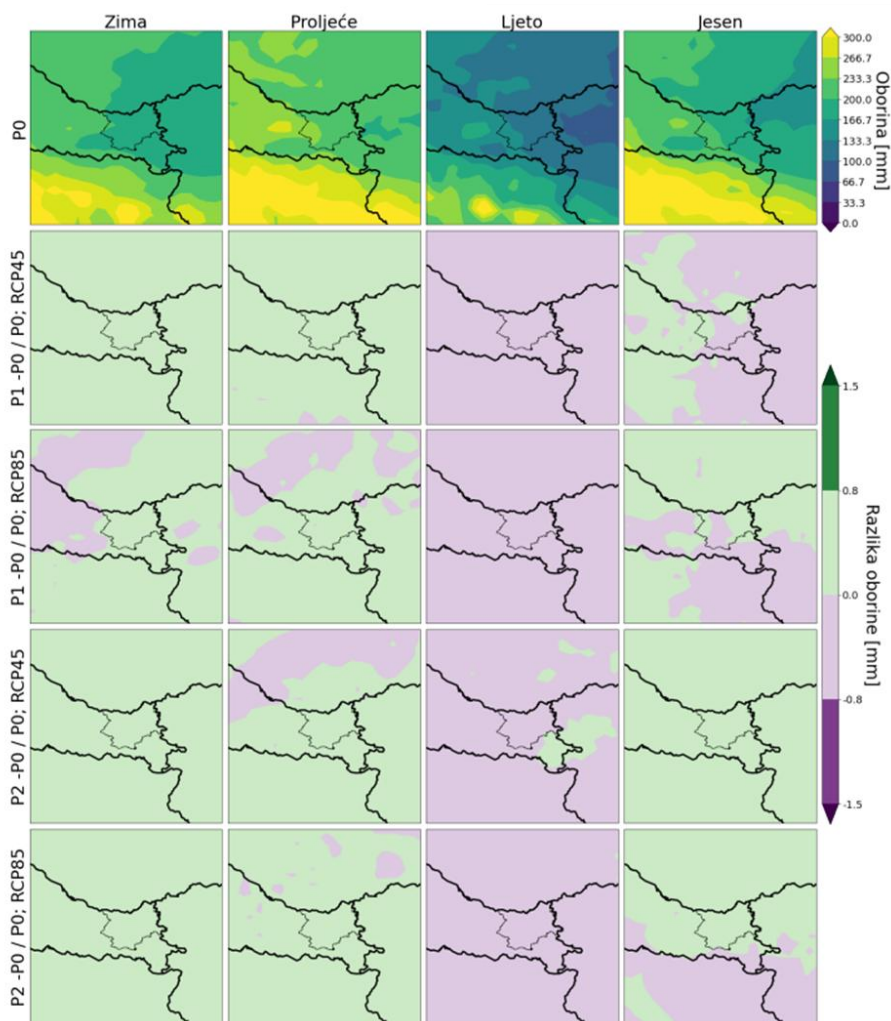


Figure 6 Median change in precipitation (mm) for Osiječko - baranjska county, based on different RegCM models, P0 - reference period (1971.-2000.), P1 - change in period 2011.-2040., P2 - change in period 2041.-2070., left to the right - winter, spring, summer, autumn autumn [1]

The selected courtyards share common physical, functional, and ecological characteristics:

Surface and materials:

Surfaces are often poorly maintained, with issues like uneven terrain, overgrown vegetation, and degraded paving. Courtyard No. 1 with about 90 % of concrete coverage and no tall vegetation, shows the highest level of heat accumulation. Surfaces of Courtyards No. 2 and No. 3 located within Tvrđa are mostly permeable, made of clay brick pavers with green patches. These pavers are largely preserved in Courtyard No. 2, whereas



in Courtyard No. 3 they are completely neglected, overgrown with low vegetation and covered with layers of soil. The pilot courtyards are covered with natural soil and grass.

Sunlight and ventilation

Courtyards within Tvrđa (courtyard No. 1, No. 2, No. 3) due to their orientation have high sunlight exposure throughout the day. This, combined with limited shade results in pronounced heat retention, especially during the summer months. Courtyard No. 1 and No. 2 lack natural ventilation as they are enclosed by surrounding buildings, preventing air circulation, and both also have minimal natural shade, with only small portions shielded by trees or adjacent structures. The use of heat-retaining materials like clay bricks in Courtyard No. 2 further intensifies thermal buildup, while Courtyard No. 3 benefits somewhat from partial vegetation and building shade, reducing heat accumulation, especially in the morning hours.

Pilot courtyards are mostly exposed to the sunlight all day (pilot 2) or until late afternoon during the summer time (pilot 1) due to their orientation. In addition, partial shade is created by surrounding buildings (pilot 1). Courtyards natural surfaces (soil and grass) and its surrounding green areas reduce heat buildup and there is natural circulation present in the courtyards mostly due to open air corridors present in the north and south side and strategic openings.

Greenery and Biodiversity

Courtyards within the Tvrđa display variable percentages of bioactive areas. Courtyard No. 1 has a minimal number of bioactive areas (up to 10%), mainly consisting of natural soil with grass, flower beds, three decorative shrubs, and four small ornamental trees. In contrast, Courtyards No. 2 and No. 3 possess relatively high bioactive area percentages (80 - 98 %), primarily attributed to permeable surfaces such as clay brick paving and natural soil with grass. Green areas constitute up to 20 % in these courtyards. Vegetation in courtyards within Tvrđa is generally sparse and unstructured. Where present, greenery it is mostly horizontal (lawns, shrubs and ruderal species), with little to no vertical greenery. Biodiversity and variety of plants is quite low and native species are absent. Pilot courtyards exhibit a high percentage of bioactive areas, ranging from 99 % to 100 %; however, the vegetation quality is suboptimal, primarily comprising ruderal species in disturbed environments. Vertical greenery is present to some extent, predominantly



consisting of spontaneous vegetation with native invasive elements. The proportion of trees is notably low, varying between 3 % and 5 %. Generally, vegetation is not well maintained and there is little botanical diversity and vertical greenery is rarely used.

Rainwater management:

Most of the courtyards already have big bioactive area, which is positive for stormwater management and natural infiltration. Despite that, irrigation and maintenance plans are lacking. In the pilot courtyards, due to the presence of natural ground cover, rainwater infiltrates naturally across the entire surface. For courtyards present within Tvrdā, drainage solutions are mostly lacking or are only partly present (drainage pipes). However, if existing, they are not appropriately positioned, e.g. infiltration green areas are not designed near the pipe outlets or properly maintained thus leading to surface runoff. This is most present in courtyard No.1 where water accumulation is expected during periods of heavy rainfall. This effect is somewhat not so evident in courtyards No. 2 and No. 3 as they have partially permeable surfaces. All courtyards lack water retention systems in place.

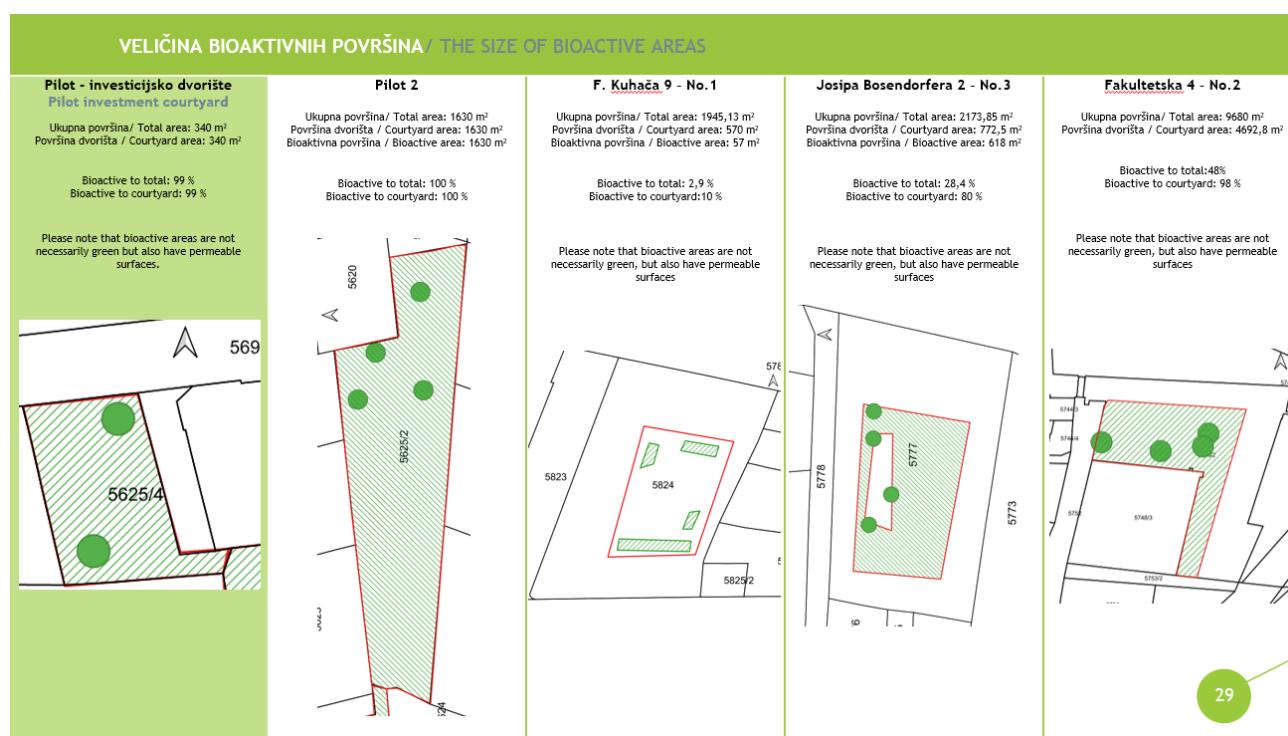


Figure 7 Bioactive areas of selected courtyards within city of Osijek, source: Chapter on courtyards



2.1.1. Urban Heat Island (UHI) and Heat Waves

The courtyards within Tvrđa exhibit significant heat accumulation due to extensive exposure to sunlight, particularly during the summer months, with vertical and horizontal surfaces amplifying this effect. Higher heat accumulation of the courtyards within Tvrđa, compared to pilot courtyards is result of several different factors - surface material of the courtyards, presence of surrounding buildings and the absence of greenery. In particular, Courtyard No. 1 with about 90 % of concrete coverage and no tall vegetation, shows the highest level of heat accumulation. Surfaces of Courtyards No. 2 and No. 3 located within Tvrđa are mostly permeable, made of clay brick pavers with green patches, however, they still exhibit notable heat build-up during peak sun exposure (from noon for courtyard No. 2, and in the late afternoon for courtyard No. 3). The pilot courtyards are covered with natural soil and grass that for the most part mitigates heat accumulation. With a documented rise in average annual temperature of approximately 1.55 °C and increasingly frequent extreme thermal conditions, the courtyards within Tvrđa, and particularly Courtyard No. 1 are becoming critical hotspots. The predominance of impervious surfaces, minimal vegetation, and dense surrounding architecture significantly contribute to heat retention. As climate change continues to elevate baseline temperatures, the lack of adaptive design and vegetation in Tvrđa's courtyards will exacerbate the UHI effect, underscoring the urgent need for sustainable interventions.

2.1.2. Torrential Rains - Water Management

In the courtyards within Tvrđa, water is directed into the courtyards by sloped surfaces, however, as drainage pipes and infiltration green areas are either poorly positioned or inadequately maintained, ineffective water removal and surface runoff is present. This problem is especially pronounced in Courtyard No. 1, where the impermeable concrete surface and improperly placed drainage outlets lead to frequent temporary flooding during heavy rainfall. Courtyards No. 2 and No. 3 experience these issues to a lesser extent due to their partially permeable surfaces, which allow for some water infiltration. In contrast, the pilot courtyards, featuring natural ground cover, enable rainwater to infiltrate naturally across the entire area, thus minimizing flooding problems. To mitigate this



problem, strategic interventions are needed, such as reducing impervious surfaces (Courtyard No. 1) and introducing infiltration zones near the pipe outlets to absorb and filter stormwater (all courtyards). Where possible, slopes should be improved so that the water is directed towards designed infiltration zones.

There are no water retention systems in place in any of the courtyards. Although introducing water retention tanks and utilizing harvested rainwater is a preferred solution for irrigating courtyard vegetation, as it reduces reliance on municipal water supplies, minimizes maintenance costs, and ensures uninterrupted water source even during summer restrictions, such solutions are not advisable and appropriate for the city of Osijek. Due to its location near floodplains and wetlands, particularly around the Drava River and Kopački rit Nature Park, the city has significant problems with heavy mosquito population. This represents both a public health concern and a quality-of-life issue during the warmer months, along with high cost for mosquito control. Standing water, such as found in water retention systems, if not properly managed, creates breeding sites for mosquitos, thus this would exacerbate the problem.

2.1.3. Nature-Based Solutions (NBS)

Courtyards are characterized by large bioactive areas in most locations, which is beneficial for stormwater management and natural infiltration. However, significant shortcomings persist, including the absence of structured irrigation and maintenance plans, sparse and poorly maintained vegetation, and limited botanical diversity. Vertical greenery is rarely used, and where present, it primarily consists of spontaneous, often invasive, species with a low proportion of trees (3 - 5 %). Pilot courtyards, while exhibiting nearly complete coverage of bioactive areas, feature suboptimal vegetation dominated by ruderal species. Courtyard No. 1 has minimal bioactive coverage (up to 10 %), mostly comprising grass, flower beds, and a few decorative plants, while Courtyards No. 2 and No. 3 have higher percentages (80 - 98 %) due to permeable surfaces, though areas with vegetation remain small. Overall, greenery is fragmented and in poor condition, offering limited benefits for cooling, air quality, or recreation.



2.1.4. Green infrastructure (GI) and biodiversity

Although all courtyards contain certain amount of vegetation, these green elements currently do not qualify as part of the city's formal green infrastructure (GI). It is essential to understand that not every green or blue space within the city automatically contributes to the GI network. For an area or element to be classified as GI, it must meet specific criteria: it should be a high - quality green or blue space that is functionally connected to other such areas, and it must provide a range of ecosystem services beyond mere aesthetics¹. At present, the courtyards, especially those within Tvrđa, do not meet these standards. The existing vegetation is generally sparse, lacks structure, is poorly maintained, and exhibits limited botanical diversity. Most greenery is horizontal (mainly lawns, shrubs, and ruderal species), with little variety and a noticeable absence of native plants. This results in low biodiversity and minimal ecological value.

For the courtyards to fully contribute to the city's GI network and maximize their benefits, substantial enhancements are necessary. These improvements should include - increasing plant diversity (with a focus on native flora), improving vegetation structure, ensuring functional connectivity to other GI etc.

Integrating the courtyards into the city's green infrastructure will not only improve their ecological value but also deliver multiple co-benefits such as reducing the UHI effect, enhancing climate resilience, improving air and water quality, and providing attractive, healthy spaces for residents.

2.2. Developing Green and blue infrastructure in Historic cities: Challenges, Opportunities and Solutions

Historic urban centres due to their urban planning and current climatic conditions as well as dense urbanization and limited green space, are particularly susceptible to UHI effect [11]. The scarcity of green spaces and the compact nature of these areas intensify the accumulation of heat, making them some of the most vulnerable locations in the context of ongoing climate change [21]. As establishing resilient and health-conscious urban landscapes is becoming an imperative to shield communities from escalating health risks

¹ Building a GI (2013). Building a Green Infrastructure in Europe. European Commission, Bruxelles



exacerbated by the UHI effect [39] historic cities are increasingly recognizing the significance of introducing adaptation strategies to maintain liveable conditions. Among the most effective approaches to mitigating UHI, is the integration of green infrastructure (GI) [1, 39], which not only helps mitigate high temperatures and enhances climate resilience but also brings a host of co-benefits such as restoring urban biodiversity, sequestering carbon, lowering energy consumption, improving air quality, reducing flood risks, and contributing to city-wide goals of climate neutrality and urban resilience by 2030. Furthermore, green infrastructure elevates quality of life by reducing noise, providing recreational and social spaces, and fostering a healthier urban environment.

The revitalisation of historic courtyards through the introduction of GBI offers a unique opportunity for site-specific interventions tailored to the context and character of each location (courtyard). Potential interventions range from straightforward actions such as tree planting, installing green roofs, and creating rain gardens, water retentions systems or pervious surfaces - to more ambitious projects like establishing urban pocket parks or more complex green spaces. For green and blue spaces within a certain territory to become green infrastructure, physical and functional connectivity between these spatial elements is crucial. Such connectivity is achieved through corridors that hold significant ecological, environmental, social, and/or climatic characteristics, enabling the mobility of urban organisms between individual green and/or blue spaces, contributing to the resolution of climate and environmental challenges, and enhancing the quality of life for residents. For urban green infrastructure to work as a strategic approach, developing interconnected and multifunctional networks of blue and green spaces to offer a diverse array of advantages across environmental, social, and economic domains is crucial.

When planning new GBI, it is essential to align interventions with the already existing spatial and functional aspects of urban green systems, integrating them into a cohesive framework that benefits both the environment and the community. By focusing on these principles, planners can create a robust strategy that not only addresses current deficiencies but also anticipates future challenges brought by climate change and urbanisation. As such, one of the first tasks is to perform the analysis of existing green infrastructure on the urban scale (city) and green infrastructure corridors.



2.2.1. Challenges of GBI in Historic Urban Fabrics

Historic city centres are among the urban areas most deficient in green spaces, with minimal vegetation cover, restricted water retention capabilities, and significant heat accumulation. The reintegration of natural elements in such locations is particularly challenging, leading to their frequent omission from urban green infrastructure strategies and poor connection to adjacent green zones. Soil sealing is extensive, as courtyards are typically surfaced with impermeable materials like stone setts, concrete slabs, or asphalt, which severely limits natural infiltration. Commonly, as observed in our project, these courtyards are repurposed as car parks or used as simple transition areas or storage, lacking both a social function and adequate maintenance [19, 40, 8].

Key challenges for introducing green and blue infrastructure (GBI) in historic urban centres include:

- **Preservation restrictions and morphological complexities:** Integration of GBI in historic areas is complex due to the compact structure and numerous heritage conservations [40]. Additionally, often, heritage preservation or city planning documents may restrict the implementation of certain interventions, such as bioretention zones or other nature-based solutions (NBS²).
- **Limited space for interventions:** Compact structures pose a challenge when trying to incorporate tall-stemmed vegetation due to proximity of buildings and little space for the development of the root system [40]. Opportunities for interventions are limited, with many surfaces sealed and the available soil often degraded, compacted, and unsuitable for plant growth resulting in low biodiversity.
- **Restrictions on vertical greenery:** The introduction of features like living walls or climbing plants is often avoided due to concerns over altering the visual integrity of historic architecture, thereby limiting the potential cooling benefits these solutions offer.
- **Poor connectivity with surrounding green spaces:** Courtyards in historic centres are mostly enclosed or semi-enclosed spaces, isolated and not connected to other

² NBS are defined as “solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience” (EEA, 2015). In literature NBS acts as an umbrella for green and green - blue infrastructure [26].



green areas. This limits their contribution to urban cooling, ecosystem services, improved air quality, and biodiversity.

- **Inadequate water management:** Historic centres generally possess low water retention due to legacy drainage systems designed for rapid runoff, not retention. Widespread soil sealing often results in flooding during heavy rainfall, highlighting the need for careful selection of climate-resilient plant species and the implementation of small-scale water retention features.

Given that Europe has been warming at twice the global rate since the 1980s, with extreme heat events now posing serious risks and expected to worsen in frequency and intensity [38], historic urban cores require tailored, site-specific solutions to address these climate challenges. However, these interventions are often demanding in terms of resources, time, and careful planning [40]. To achieve meaningful adaptation in historic cities, an integrated approach to incorporating green infrastructure within these unique urban landscapes is essential.

Despite certain limitations, historic cities offer considerable opportunities for the development of green and blue infrastructure. Courtyards, as public or semi-public spaces open spaces can be transformed into thoughtfully designed green spaces that function as focal points for cooling, improved stormwater management, and increased biodiversity, making them a part of the city's overall green infrastructure. Implementing such measures not only advances the city's wider sustainability objectives but also improves urban quality of life by providing residents with welcoming, accessible communal areas. In addition, their moderate scale makes them ideal for pilot projects, which can then be replicated across wider neighbourhoods. Key opportunities include:

- **Replacement of impermeable surfaces with permeable ones:** Due to the extensive soil sealing present in historic centres, as well as courtyards often used as parking lots, the most effective are structural solutions that include the reshaping of the present cover [40], i.e. replacement of impermeable surfaces with permeable ones. This also makes an important contribution to stormwater management and the substitution depends on the historic and urban constraints. Ideally, all impermeable surfaces should be substituted with permeable materials, but if not possible, partial smaller interventions are recommended.



- **Expanding the greenery structure:** To enhance ecological value, it is essential to introduce new green spaces within courtyards, placing particular focus on tall vegetation such as deciduous trees with broad canopies that offer natural shade. When planning new green areas, mixed plantings - such as shrubs, perennials, flower beds, ground covers etc. is essential to support biodiversity and create visually appealing green spaces. However, it is important to acknowledge that, due to restricted space and limitations for root development in historic settings, the selection and placement of tall-stemmed vegetation must be carefully considered to avoid conflicts with existing structures. When choosing the type of vegetation to be incorporated, it is crucial to consider the microclimate and effect of climate change, implement native species, and keep in mind the spatial considerations - lack of space, soil etc.
- **Integrating vertical greenery:** In cases where horizontal space is limited or heritage preservation restricts the use of tall-stemmed trees, the integration of vertical greenery offers an effective solution. Options such as vegetated pergolas, green facades, raised plant supports, living walls, or cascading plants. If heritage constraints prevent the installation of vertical greenery on primary building facades, these features can be sensibly positioned on less prominent partition walls, fences, or by adding new climbing structures like wooden posts. Integration of vertical and horizontal greenery is considered an important factor in improving the cooling effects of courtyards.
- **Integrating greenery on auxiliary structures:** Incorporating green roofs on auxiliary buildings like garbage or storage sheds, as well as other accessory structures, is another method to expand greenery. Vertical greenery or hedges can also be strategically placed to screen garbage containers from view. By using green features such as trellises covered in plants, existing waste management areas can be visually improved and better integrated into the courtyard environment.
- **Improving the accessibility and connectivity.** Urban courtyards should ideally function as public spaces, thus emphasizing their role in enhancing urban greenery and providing accessible, pleasant communal areas. Improving the accessibility and connectivity of courtyards is essential for maximizing their benefits and role in



climate change adaptation. To fully integrate revitalized courtyards into the urban green network, it is vital to ensure they are open to the public. In cases where courtyards are surrounded by residential buildings, a semi-public approach can be applied. Additionally, integration of courtyards with other elements of urban green infrastructure is crucial for creating a cohesive and functional urban green network. Courtyards should be used as links to the broader system thus connecting larger patches of greenery such as parks, tree-lined streets, and other green spaces to enhance ecological benefits and urban resilience.

- **Encourage community engagement:** By creating opportunities for residents and stakeholders to participate in courtyard design, innovative, multifunctional green spaces can be created. Engaging residents not only enhances social cohesion and a shared sense of place but also encourage such actions to be replicated in other parts of the city.

2.2.2. Key Steps in Revitalizing Courtyards with GBI

Developing effective GBI strategies in historic courtyards requires a systematic approach that balances technical precision with community and heritage sensitivity.

The process involves several stages:

- **Spatial analysis of existing GBI of the wider city.** This step is crucial to identify gaps or fragmentations of green and blue infrastructure of the city. This analysis serves to identify the critical areas for revitalization and to address the gaps in connectivity (corridors) as well as to determine whether additional small green spaces (i.e. stepping stones) are required to ensure the functionality and interconnectivity of GI network.
- **UHI analysis.** In historical urban centres, due to being highly stratified and dense, UHI is even more prominent [9]. UHI is characterised by higher surface and air temperatures in urban areas, compared to the surrounding natural/rural areas and this effect is especially problematic in the summer season, when the consequences of heat waves are often amplified. As such to determine the intensity of UHI phenomena, building density, surfaces, green space, and average building height



should be examined [30]. This helps determining possible solutions to mitigate urban heat islands.

- **Site assessment.** A thorough inspection of the courtyard and its microclimatic conditions, especially in terms of sunlight exposure, natural ventilation, surfaces (impervious/pervious, condition), NBS, water runoff is necessary, along with inventory of existing greenery (type, amount, etc) and water elements, and historic and contemporary materials is necessary. This serves as the foundation for potential interventions.
- **Archival and technical research.** Such research is essential for identifying the specific constraints and possibilities associated with transforming courtyards in historic urban areas into green spaces. This process should involve gathering relevant documentation, understanding conservation and heritage regulations, and reviewing both current and proposed GBI development and maintenance plans. This is crucial to determine limitations related to the creation of permeable surfaces, the feasibility of implementing nature-based solutions, the introduction of taller vegetation, and the overall development of urban greenery. The proposed design should integrate greenery in a way that ensures visual and spatial harmony with the historical context by respecting the original scale, the relationships between open and built spaces, and the structural features of architectural components. The design should enable a balanced coexistence of preserved historical compositions with new interventions. This step ensures that any proposed interventions respect heritage value while maximising ecological and social benefits.
- **Community involvement.** Public engagement ensure that residents expectations and needs are incorporated into the design and that multifunctional spaces that will be used by the local communities are created.
- **Concept development.** Designers select most appropriate type of GBI, NBS and and infrastructural solutions that balance ecological, aesthetic, and social considerations.

This structured process ensures that proposed measures are both technically feasible and socially acceptable, while respecting heritage values.



2.2.2.1. GBI spatial analysis

It is well known that the presence and arrangement of green areas significantly influence the intensity of the UHI effect [39] and that scattered small patches of greenery do not mitigate as nearly as contiguous and densely vegetated green areas [9]. The ecological benefits and resilience of urban areas rely on the effective integration of small-scale GI such as courtyards within a broader GI network. For green and blue spaces within a certain territory to become green infrastructure, physical and functional connectivity between these spatial elements is crucial. Such connectivity is achieved through corridors that hold significant ecological, environmental, social, and/or climatic characteristics, enabling the mobility of urban organisms between individual green and/or blue spaces, contributing to the resolution of climate and environmental challenges, and enhancing the quality of life for residents.

To maximise the effectiveness of green and blue infrastructure (GBI), it is critical to analyse the existing network comprehensively and identify gaps or fragmented connections. This helps identify the critical areas for revitalization and to address the gaps in connectivity (corridors) as well as to determine whether additional small green spaces (i.e. stepping stones) are required to ensure the functionality and interconnectivity of GI network. Usually, such information can be derived from the Green Infrastructure Registries of the city.

The development of urban green infrastructure in Osijek is based on a nodal approach, where areas of public greenery (parks, gardens, etc.) become the hubs of urban green infrastructure. This, in accordance with other factors such as better accessibility focused the identification of the courtyards suited for revitalization. In addition, GI Strategy envisions to enhance the inherited identity values of Osijek as a green city, with the goal of improving the relationship between the built and natural environment. This development aims to intertwine various environmental components to enable equitable growth, ensuring that residents benefit from the advantages of the natural surroundings and the well-being provided by green infrastructure.



At the time of writing this document, the city of Osijek had not yet entered data into the national GI Registry³ thus a local green cadastre of city⁴ was used, that contains certain elements such as grasslands, trees, bushes and water fountains are listed. To ensure effective planning, revitalization, and long-term sustainability of future revitalizations of courtyards with GBI, it is essential that future analyses and interventions rely on the accurate, comprehensive, and standardized data.

Spatial analysis of existing GBI in the city of Osijek, revealed a critical deficiency of green spaces in the core of Tvrđa. While peripheral zones of Tvrđa exhibit presence of green areas - mostly grasslands, the central area (core) is devoid of vegetation (except for a few trees), thus being vulnerable to intensified Urban Heat Island (UHI) effect (Figure 8, Figure 9). This effect is exacerbated by rising temperature anomalies recorded by the Croatian Hydrometeorological Institute, with deviations of the mean air temperature reaching from 0.7 °C in 2020 to maximum of 2.5 °C in 2024 compared to the 1981-2010 normal (data was looked at the period 2020 to 2024). This is felt the most during the summer months. In addition, the courtyards within Tvrđa are not connected to other green areas and Drava River, thus their spatial location provided huge potential to restore ecological continuity. Through revitalization, these spaces could present new urban green hubs within the core of Tvrđa. Specifically, courtyard No. 1 could serve as a critical stepping stone, improving ecological flow toward the green corridors to the south and southwest. Courtyard No. 2 could help anchor connectivity toward the green grasslands (lawns) surrounding the fortress and the Drava River to the north and northeast. Courtyard No. 3 could function as a linking node, facilitating vertical connectivity between northern and southern green areas.

³ National Green Infrastructure Registry within the Information System for Spatial Planning (ISPU) is being developed, where all local government units are required to input Green and Blue Infrastructure (GBI) data for their areas. The objective of this Registry is to establish a unified and transparent system for determining the initial conditions and monitoring the development of green infrastructure on a national scale. In addition to analysing spatial data regarding GBI, this registry will serve as the foundation for developing strategic documents for local government units and their spatial plans. The purpose of this registry is to ensure that by 31 December 2030, there is no loss of urban green areas or tree canopy coverage in cities. This requirement arises from Regulation (EU) 2024/1991 on Nature Restoration dated 24 June 2024.

⁴ It is important to note that this register is quite old and does not contain all the necessary information which is needed for the national register. Despite this, it was used for the purpose of this document, as it was, along with spatial planning graphics, the only available source of data.



In addition, with the connection of courtyards No. 2 and No. 3 a continuous, linear green corridor through the eastern part of Tvrđa could be formed. If connected, these two courtyards could become a central segment in a vertical green axis that runs north-south across Tvrđa. This could help close one of the most critical connectivity gaps - between the open grasslands along the Drava River and the greener urban areas to the south of Tvrđa. With these two courtyards a larger green space could be created, that will help mitigate the UHI effects more effectively than isolated green pockets. In addition, it will present an important ecological corridor, thus enhancing the biodiversity of both courtyards. Together, if revitalized, courtyards could create a cohesive vertical ecological corridor through the heart of Tvrđa, linking peripheral green areas and the Drava River waterfront. This network could enhance biodiversity, mitigate UHI effects, and improve life of inhabitants and visitors. According to Green Infrastructure Strategy of Osijek, connectivity of green spaces (green urban corridors) is preferred to be achieved with tree-lined networks. This concept relies on revitalization of existing and planting new tree lines where such are absent or discontinuous. Historically, tree-lined avenues served as essential features in urban landscapes, providing not only aesthetic appeal but also benefits such as shade, improved air quality and a sense of structure within cities. Strategically, tree lines serve as natural connectors, linking fragmented green and blue spaces and integrating urban and suburban spaces into one green infrastructure network, while preserving the historic heritage. To successfully integrate new, revitalized, courtyards, it should be considered how new tree lines could be planted to ensure that full potential of mitigation of UHI is achieved.



Informacijski sustav prostornog uređenja
Prikazani slojevi: Ostale države (USGS), Digitalna ortofoto karta 2021.-2022., Obuhvat prostornog plana, Korištenje i namjena prostora/površina
Mjerilo: 1:5000

Figure 8 Green areas - marked with Z and Z1 within the administrative borders of Tvrdá in relation to selected courtyards (red).



Legend

- Courtyards for Strategy
- Trees
- ▲ Shrubs
- Grassland

Figure 9 Location of courtyards selected for strategy in regards to the local GI register and amount of green areas within Tvrdá core



Pilot courtyards within the Gornji Grad („Upper Town“), are located between the public and residential area on the south and larger distinguished green areas (mostly lawns) located north, north-east, along the banks of Drava river. This area is designed for mixed use (M).

When revitalized these courtyards will provide a connection to the green area (park) located to the west. They have the potential to enhance the spatial connectivity of Osijek's inner urban fabric, thus forming a cohesive and multifunctional green infrastructure. Vertically, they will create the link between the riverfront and the large green area (Z1) located east of pilot courtyards and horizontally, they will improve lateral connectivity between small green pockets located west and larger Z1 zones on the east. In addition, they will function as a transitional green buffer between the residential and public buildings and the riverfront. As two of the pilot courtyards are located in close proximity, they will be physically and ecologically connected, thus forming a larger continuous green area within the built urban matrix. This integration will transform isolated courtyards into a cohesive green hub, which will serve as a key node within the broader GI network. When connected, they will have bigger cooling potential thus mitigating the effects of UHI.



Informacijski sustav prostornog uređenja
Prikazani slojevi: Ostale države (USGS), Digitalna ortofoto karta 2021.-2022., Korištenje i namjena prostora/površina
Mjerilo: 1:5000

Figure 10 Green areas - marked with Z and Z1 within Gornji Grad in relation to selected pilot courtyards (red).



Legend
● Trees
▲ Shrubs
■ Grassland

Figure 11 Location of pilot courtyards selected for strategy in regards to the local GI register



In addition to the connectivity and potential to create coherent green and blue network, when selecting courtyards for revitalization using green infrastructure, the size of the area plays a pivotal role. For this project, the minimum size of 300 m² was considered as a threshold that allows for the introduction of GBI elements. The total and functional size of the courtyard directly affects the feasibility, cost, and scope of such projects, particularly when there is a defined timeframe of five years. Even though, larger areas (courtyards) offer greater potential for diverse bioactive areas - wider benefits in terms of cooling, stormwater management and biodiversity potential, they also come with increased planning and maintenance challenges. The size of the courtyards determines both the scale of bioactive surface areas and the extent to which green infrastructure features can be incorporated, along with the preservation of historic values. On the other hand, smaller courtyards, like the selected pilot courtyards, are more likely to see full implementation within the given timeframe, thus allowing the deployment of GBI in strategic places to enhance the existing GBI network of the city.

Selected courtyards for city of Osijek range in size from 340 m² (pilot courtyard 1) to maximum of 4692,8 m² (courtyard No. 2). Despite their relatively small size, the pilot courtyards and the courtyards within Tvrđa have been strategically selected for revitalization due to their critical role in enhancing the spatial connectivity of existing green infrastructure. In addition, the smallest pilot courtyard was envisioned to be connected to the pilot No.2 thus creating bigger green areas. Scientific studies underscore the importance of creating larger interconnected green spaces, and as such, the possibility of connecting smaller green areas should be one of the key factors to be considered when selecting courtyards for the revitalization with GBI.

2.2.3. Possible Solutions - from surface type and permeability to greenery structure

Surface Type and Permeability

The type and permeability of courtyard surface directly influence stormwater infiltration and helps with mitigation of UHI effects. Due to the extensive soil sealing present in urban areas and especially historic centres, total replacement of impermeable surfaces with permeable ones is preferred.



If such solution is not feasible, partial solutions such as small rain gardens or creating patches of grass or infiltration strips should be considered. Alternatives for replacing part of impervious such as sedum turf, grass pavers, gravel and sand surfaces or porous concrete/asphalt should also be considered. If removing portions of impermeable surfaces is not an option, planting pits (planter boxes) with vegetation and similar solutions should be incorporated as an alternative. Additionally cooling effect of impervious surfaces could be achieved with increasement of albedo. Light coloured materials such as gravel and reflective materials could be implemented. These actions will enhance both water management and microclimate regulation.

Courtyards with high levels of impermeable surfaces and poor drainage for adaptation interventions should be prioritised for surface reshaping.

Greenery Structure (Horizontal and Vertical)

The presence, type, and condition of greenery are critical elements that provide ecosystem services such as air purification, stormwater management, carbon sequestration, and biodiversity enhancement as well as shading and cooling in small urban spaces, where evapotranspiration is limited.

Green areas should consist of various types of vegetation to promote landscape diversity and biodiversity (e.g. flower beds with native wildflowers should be introduced to at least part of the courtyards to boost biodiversity of pollinators and if possible, shrubs and perennials should also be included within the green areas). Tall vegetation, in form of deciduous trees is recommended with a preference to the species that create large canopies. However, given historical context, it is acknowledged that tall-stemmed vegetation may not always be suitable. Therefore, integrating vertical greenery with horizontal greenery is considered an important factor in improving the cooling effects of courtyards. In historic courtyards several options could be considered for adding structure, such vegetated pergolas, green facades, elevated plant support structures, living walls, flowing vegetation etc.

When choosing the type of vegetation to be incorporated, it is crucial to consider the microclimate conditions such as sunlight exposure, humidity, wind patterns, as well as the occurring climate change effects such as more intensified extreme weather effects, increase in temperature, loss of snow coverage etc. When choosing the most appropriate



species, spatial considerations such as lack of soil, low quality of soil etc. should also be considered. Native plants species that are heat tolerant and are allergen free are preferred. Boosting native plant diversity is emphasized, and preference should be given to pollinator friendly species.

Courtyards without tree canopy, diversified greenery, or with poorly maintained vegetation should be prioritised for interventions.



Figure 12 Integration of diversified greenery for pilot courtyards in Osijek

Specific solutions include:

Diversifying greenery - in courtyards different types of vegetation will be implemented consisting of taller vegetation (trees where appropriate), shrubs, flower beds, perennials, aromatic species etc. Vertical greenery will also be added through implementation of living fences (e.g. *Taxus* sp.) and where possible with climbers and vines species. Depending on the urban and historic restrictions, vertical greenery can be included on less significant partition walls, fences or by adding new climbing elements for plants. For instance, metal or wooden support structures could be introduced, which could be either freestanding or placed near the walls without being physically attached to it.



These structures would serve as support for climbing plants. The introduction of green walls and vertical plant structures, could also be implemented, at least partially, in courtyards No. 1 and No. 3. In Courtyard No. 2, due to the well-preserved condition of the existing walls - which contribute significantly to the visual identity of the area and the status of cultural heritage, such interventions are not recommended.

Improving the quality of green areas - present invasive vegetation in the courtyards, should be adequately removed and the quality of soil and grassy areas should be improved with substrates and appropriate gardening techniques to prevent further development of ruderal vegetation. Mature and healthy vegetation should be preserved, and green areas should be improved by introducing various native plants and floral elements to enhance the aesthetic value of the space and boost biodiversity (pollinators). In addition, eco-friendly land management practices, such as structural pruning, unmown patches (mowed only once or twice a year to create wildflower meadows etc.), non frequent mowing (to allow plants to flower and produce seeds, not cutting grass below 10-15 cm), non frequent hedge management etc. should be considered for courtyards. This helps boosts urban biodiversity as it has been recognized that traditional ways of maintenance such as tree topping (i.e., removing all thinner branches with foliage), intensive grass cutting etc. are not appropriate in promoting urban biodiversity. Simple solutions such as insect hotels, birdhouses should also be considered to support biodiversity.

Connectivity and coherence of GI - when revitalized, the courtyards within Tvrđa will help bridge the connectivity gaps between the green grasslands along the Drava River and the peripheral green areas to the south and southwest of the core. In addition, when revitalized, they will form a more continuous green corridor, creating a vertical ecological axis through Tvrđa. This integration will transform isolated green spaces into a cohesive green network, providing larger cooling potential and mitigating UHI effects more effectively. Similarly, the pilot courtyards in Gornji Grad will serve as transitional buffers between residential zones, public spaces, and larger green areas, creating both vertical - linking the Drava riverfront to the green zone situated to the east, and horizontal links - improving lateral connections between smaller green pockets to the west and the larger green zones to the east. In addition, as two pilot courtyards will be connected to one another, they will provide ecological and social benefits of larger green areas in terms of cooling potential, support of biodiversity and social function. Additionally, revitalization



of pilot courtyards should be aligned with the restoration of Art Nouveau gardens in surrounding buildings as this presents a unique opportunity to merge cultural heritage with ecological resilience. This synergy amplifies the impact of each separate initiative, creating multifunctional green spaces that are not only beautiful and historically significant but also resilient and socially inclusive.

Permeable surfaces and drainage - replacement of concrete with permeable paving, at least partly is advisable for Courtyard No.1. to reduce UHI and surface runoff. This could be achieved through introducing new water-permeable paving (e.g. open-jointed bricks, gravel-bound surfaces, grass pavers, gravel and sand surfaces or porous concrete/asphalt) or through creating additional patches of grass, infiltration strips small rain gardens etc. As, surfaces of Courtyards No. 2 and No. 3 are made of clay brick paver. These pavers are largely preserved in Courtyard No. 2, whereas in Courtyard No. 3 they are completely neglected, overgrown with low vegetation and covered with layers of soil. It is necessary to retain and protect the original brick paving in Courtyard No. 2 and integrate new green areas. Accumulated soil and vegetation from existing brick surfaces in courtyards No. 2 and No. 3 should be removed and clay paving in courtyard No. 3 should be repaired. Drainage in courtyards is mostly natural and drainage solutions such as drainage pipes, where present, are not appropriately positioned - infiltration green areas are not designed near the pipe outlets, except for courtyard No. 2. or maintained thus leading to surface runoff. It is advisable to introduce infiltration zones near the pipe outlets. In addition, improvement of slope should be considered, where appropriate, so that the water is directed towards designed infiltration zones.

Improving accessibility - to effectively integrate revitalized courtyards into the urban fibre, it is crucial that they are transformed into public green spaces. This includes opening the courtyards to the public and improving accessibility. To facilitate transformation and ensure also long-term legal protection from future land-use conflicts it is recommended that the revitalized courtyards are reclassified and designated as public green areas within official spatial plans. Due to specific spatial characteristics of selected courtyards of Osijek, a semi-closed access model is deemed most appropriate as it balances the functionality of the courtyards as shared spaces, historic value and needs of residents. This approach means that courtyards are open to the public within the specific time of the day and closed at night). For greater flexibility and broader utilization of



public green spaces, closing hours of the courtyards within Tvrđa should be adjusted to accommodate special events, such as art exhibitions and similar activities. Another important aspect is ensuring the accessibility and inclusivity of all citizens. This aspect is specifically related to limited accessibility for people with mobility impairments. Through the revitalization, courtyards will be adapted to ensure accessibility for persons with disabilities and those with mobility impairments. Barriers such as thresholds and metal obstructions at entrances will be removed and accessible pathways (made of stable, non-slip materials) through the courtyards will be created. Resting areas along pathways should be considered and benches with backrests and armrests should be strategically placed for those who may require frequent breaks. All planned interventions should be carried out with special attention to the preservation of historical and ambient elements, using materials and design solutions that respect the cultural and historical character of the site. For the pilot courtyards, the proposed design solution has considered the accessibility needs of people with mobility impairments, ensuring no level differences and adequate availability of all elements according to the valid technical regulations on building accessibility for disabled persons and persons with reduced mobility.

Generally, when planning and managing GBI, five fundamental principles should be included - development of GBI across multiple scales, ensuring multifunctionality, fostering strong connectivity with other GBI, integrating with other urban systems, and promoting diversity [7,20]. Together, these principles maximize ecosystem services, support biodiversity, and enhance quality of life in urban environments.

2.3. Participatory approach

When planning revitalization (adaptation) of historic courtyards with green and blue infrastructure, participatory approach is vital to ensure inclusivity. In addition, literature has shown that community involvement can impede small scale GI, i.e NBS development [41]. An effective participatory planning approach blends a bottom-up process, addressing visions, needs, knowledge and recognized issues by real users of courtyards. It serves to produce solutions (designs) that include knowledge-based decisions and designs that are applicable and realistic. To foster meaningful community engagement, it is essential to maintain active dialogue with local residents throughout the planning stage, encouraging them to express their thoughts and allowing them to have a direct influence on decision-



making [6,17]. Properly conducted social participation results in counteracting conflicts, and appropriate early consultation is an effective element of diagnosing the space that is to be covered by the revitalization process.

When creating design for the courtyards, functionally and use of space should be kept in mind. Engaging residents in the decision-making process is essential, as their inputs help identify specific needs and encourage creative, multifunctional uses for these spaces. Enhancing community involvement has been identified as a key factor in preserving the inner courtyards as green urban oases. This approach not only helps define the future use of courtyards but could also support their ongoing maintenance, ensuring the long-term sustainability of revitalized spaces beyond the project's duration. Stakeholder engagement is also emphasized as an integral part of the development of GI Strategy for the City of Osijek. Concerns include reducing green areas in favour of construction, poor maintenance of existing greenery, and its deterioration during infrastructure projects.

Public consultation process was done for pilot courtyards in city of Osijek in February 2025, through questionnaires and interviews with residents, where it was decided on the intended use of space, its accessibility and atmosphere. For the pilot courtyards public consultation findings indicate that these areas are envisioned as intimate green spaces with a semi-open model. This was reflected in the proposed design solution, envisioning the pilot courtyards as intimate reading spaces, known as the „Park of Writers“. For this project, public consultations are envisioned at three stages - diagnosis, conceptual design agreement and implementation investment. The aim is to continuously inform and evaluate interventions through ongoing feedback on the project's validity, design, and execution on the project, the design concept and the implemented investment. Stakeholder engagement is responsibility of City of Osijek. For revitalization of courtyards within Tvrđa, public consultation process is needed to ensure that courtyard revitalizations meet user needs and support responsible, adaptive management of green and blue spaces, promoting ownership and sustainability.



Figure 13 Public consultation process in Osijek, February 2025

3. Strategic framework

3.1. Development Strategy of Urban Agglomeration Osijek until 2027

This strategy is a key planning document for the development of Osijek and its 19 surrounding municipalities, guiding their transformation into a modern, sustainable urban region. Through consultation process and analysis, it addresses demographic, economic, environmental, and social challenges. By 2027, Osijek aims to be eastern Croatia's urban centre, integrating city and surroundings along the river as a unified area for living, learning, working, recreation, and visiting for all generations. The city and its agglomeration aim to offer a rich array of social, cultural, and sports amenities within a preserved and diverse environment, supported by a dynamic, innovative, and sustainable economy.



The development goals focus on three strategic priorities:

- **A healthy, culturally rich, and socially active lifestyle for all generations** - by improving the quality and accessibility of health, social, cultural, and recreational services.
- **A dynamic, innovative, and sustainable economy** - by fostering innovation, supporting green and digital transformation, and strengthening the role of education and research.
- **A connected, preserved, and green living space** - by investing in green infrastructure, sustainable mobility, energy efficiency, and the protection of natural and cultural heritage.

Through these priorities, the strategy seeks to retain and attract residents, enhance the quality of life, and position Osijek as a competitive alternative to larger urban centres, all while ensuring environmental sustainability and social inclusion. The vision is underpinned by the principles of partnership, inclusivity, and alignment with national and European development frameworks, including the European Green Deal and the National Development Strategy of Croatia 2030.

The development of the urban environment is a horizontal theme for the development of the Osijek Urban Agglomeration, through effective management and improvement of the environment, ecology, and the quality of air, water, and soil. Strategic planning for 2021-2027 must consider the need to maintain and improve communal infrastructure, mobility, connectivity, and environmental protection.

The quality of the urban environment is reflected in environmental indicators, especially the state of air, water, and soil, which are crucial for a high quality of life and the foundation for sustainable agriculture, particularly in smaller, rural JLS. Key points related to development of GBI include:

Achieving appropriate urban environmental quality and mitigating ecological and climate risks requires integrated management of natural and urban environments.

Addressing environmental in a coordinated, systematic and integrated way and developing research capacities and cooperation between science, the private sector, and public administration.



Green infrastructure is a comprehensive asset, with benefits extending beyond tourism or economic attractiveness, impacting social, cultural, sports, and artistic life.

Osijek is known for its tradition of park architecture, but the share of green infrastructure is not satisfactory; more systematic and targeted strategic management is needed, including projects for the renewal of city and municipal centres and park architecture.

The strategy recognises key challenges that include improving communal infrastructure, digitalisation, green infrastructure, risk management, and waste management. For addressing these challenges, green infrastructure and natural heritage are seen as major assets for sustainable development, tourism, and branding.

3.1.1. Resilience, Safety, and Sustainability of Urban Space

One of the key investments through the ITU mechanism is planned in green urban infrastructure and the green development of the city centre. An integrated project is planned for the revitalisation of Osijek's city centre, including the improvement of public spaces and horticulture, pedestrian and cycling areas, and the installation of children's playgrounds as well as comprehensive reconstruction of key urban areas like the Retfala district and Osijek Market.

Building resilient, safe and sustainable urban spaces is recognized and specified as a **Special Objective 3.3: Resilience, Safety, and Sustainability of Urban Space.**

This included key Measures and Actions:

Development of Green Public Infrastructure - Systematic investment in the creation and enhancement of green spaces, including parks rich in biodiversity, permeable ground covers, green walls, green roofs, and green schoolyards. Projects include the physical renewal and safety improvements of public spaces and the city core, as well as the preservation of natural heritage and biodiversity in urban areas.

Preservation of Natural Heritage and Biodiversity - Emphasis on maintaining Osijek's attractive and valuable natural environment along the Drava River, traditional parks, and authentic architectural heritage.



Disaster Risk Reduction - collaboration among local government units (JLS) on research and prevention of harmful events (e.g., mosquito problems, floods) and the organization of civil protection systems.

To further strengthen the city's resilience, particularly in the context of climate change, several other specific objectives have been established. Special Objective 3.1, Improving Transport and Information Connectivity and Supporting Sustainable Transport, focuses on the construction and enhancement of pedestrian, cycling, and e-cycling infrastructure across the area - including new and upgraded cycling paths and pedestrian-bicycle bridges, as well as the introduction of sustainable public transportation. Special Objective 3.2, Promoting Energy Efficiency and Renewable Energy Sources, directly targets the reduction of environmental impact and adaptation to shifting climatic conditions. Special Objective 3.4, Green and Clean Utility Systems and Infrastructure - emphasizes the development of sustainable waste management systems and investments in clean, sustainable water supply and wastewater infrastructure. Additionally, Specific Goal 1.2 aims to create a high quality of social life for citizens in urban areas through innovative pilot projects at both neighbourhood and municipal levels, ensuring an integrated and inclusive approach.

Focused investments within Special Objective 3.3: Resilience, Safety, and Sustainability of Urban Space include:

- Development of green public infrastructure,
- Investments in the physical renewal, improvement, and safety of public spaces, as well as the revitalisation of the city centre,
- Preservation of natural heritage and biodiversity in urban areas,
- Reducing the risk of natural disasters and hazards, including cooperation between local government units (LGUs) in researching and preventing harmful events (such as mosquito problems) and disasters (like floods), as well as organising civil protection systems.

Expected Outcomes by 2029 are:

25 hectares of newly arranged public/green spaces.



Increased recycling rates (55 %) and reduced greenhouse gas emissions (by 10 % from 2018).

Enhanced resilience to climate change and natural disasters.

3.1.2. Planned Strategic Projects for Osijek in Connection with Building a Climate-Resilient City

The strategy outlines strategic projects for 2024-2027 designed to help mitigate climate change:

- Urban Centre Renewal: Pedestrianisation and landscaping of Županijska Street, Trg pape Ivana Pavla II, and Trg A. Starčevića, including green spaces and playgrounds.
- Park and Sports Complex Revitalisation: Complete renovation of Zrinjevac Park and Gradski vrt, with energy-efficient buildings, green facades, and new green areas.
- Expansion of Cycling Infrastructure: Multiple new and upgraded cycling and pedestrian paths across Osijek and surrounding municipalities, improving connectivity and promoting green mobility.
- Green Market and Public Spaces: Reconstruction of the main market (Tržnica) with energy efficiency measures and landscaping of surrounding public and green spaces.

Strategic specific projects include:

34. Redevelopment of Osijek City Centre

This project aims to turn current Županijska Street into a pedestrian zone, as well as landscaping of two squares (Trg pape Ivana Pavla II, Trg A. Starčevića) through creation of new public and green spaces, pedestrian and cycling paths, and children's playgrounds. The project aims to reduce car traffic, promote sustainable mobility, and enhance the urban microclimate with green spaces, making the city centre more resilient to climate impacts.

13. Revitalisation of Zrinjevac Park and Sports Hall

This project involves complete energy renovation of the public sector building (ŠD Zrinjevac) to increase energy efficiency, including the installation of a public bicycle system station, partial renovation of green areas, transformation of a public parking lot



into a green parking area, and the revitalisation of neglected green spaces with new lawns and plantings. The project aims to enhance urban green infrastructure, promote sustainable mobility, and improve the energy performance of public buildings, directly contributing to climate adaptation and urban cooling.

12. Reconstruction of the Gradski vrt Complex

The project includes the reconstruction of the Gradski vrt park and the development of open sports fields. The adaptation of existing stadium fields for athletics will create conditions for additional sports and recreational activities, enabling the hosting of national and international competitions and other community events. The revitalisation of this large green and sports area supports urban resilience by increasing green space, promoting active lifestyles, and providing a buffer against urban heat.

33. Reconstruction of Osijek Market

The goal of the project is to renovate and expand the main market at Trg Ljudevita Gaja, Osijek, to enable cost-effective operations and reduce maintenance costs, while also improving the surrounding public space. Activities include a comprehensive renovation of the existing market building with energy efficiency measures and renewable energy sources, as well as the arrangement of public and green areas. This project directly supports climate resilience by reducing energy consumption, increasing green space, and promoting local food systems.

3.2. Green Infrastructure Strategy of Osijek

City of Osijek has adopted Green Infrastructure Strategy for the period from 2022 to 2032. This document was designed to guide the development of green infrastructure over the next decade in Osijek. It responds to the challenges of increasing urbanisation, loss of natural and cultural landscapes, and the urgent need for sustainable urban development. The strategy recognises the city's unique identity as a “green city” and aims to enhance the inherited relationship between built and natural environments, ensuring that residents benefit from the ecological, social, and economic values of green infrastructure.

This document outlines the vision for Osijek - **“City of Osijek - the Green Meander of the Drava River”**. The vision combines the city's natural-geographical identity, shaped by the meandering Drava River, with its cultural and artistic heritage. It aims to reaffirm the



river as a unique natural and cultural phenomenon and to intertwine urban and natural processes, promoting green development principles for future.

Document outlines specific objectives, measures, priorities, and actions to guide GBI development and improve green infrastructure, based on detailed analysis of environmental resources.

Strategy is structured around four main strategic objectives (A, B, C, D), each with specific objectives and measures:

- Conservation and Enhancement of Biological and Landscape Diversity
- Improvement of Urban Space Quality through Green Infrastructure
- Mitigation and Adaptation to Climate Change through Green Infrastructure
- Planning and Management of Green Infrastructure Development

Specific objectives within the strategic objective A. include: Conservation and enhancement of protected areas and valuable habitats and Establishment of ecological corridors and restoration of damaged landscapes.

Specific objectives within strategic objective B. include: Improvement of public space quality (through improvement and development of new urban green spaces) and enhancement of the city's identity as a city of parks and gardens and improvement of quality of life.

Specific objectives within strategic objective C. include: Mitigation of climate change impacts (new green corridors in transport system), adaptation to climate change (through green infrastructure and establishment of adaptation standards for planning and design) and monitoring the impacts of climate change

Specific objectives within strategic objective D. include: Implementation and management of green infrastructure development (establishment of systems for implementing green infrastructure in sectoral (public) policies, improvement and establishment of tools for monitoring green infrastructure development) and Education and raising awareness of sustainable development through green infrastructure.



3.2.1. Improvement of Urban Space Quality with GI and adaptation to climate change

Strategic objectives B and C are closely connected, working together to both mitigate and adapt Osijek's urban environment to the challenges posed by climate change. These objectives aim to elevate the city's quality of life through a comprehensive approach to green infrastructure development and revitalisation.

Guidelines and Principles for actions within this strategic objective are:

- Enhance and Connect Green Spaces.
- Improve existing parks, gardens, and tree-lined avenues.
- Create new public green spaces, particularly in the city center.
- Integrate all green spaces into a unified, multifunctional network
- Expand and improve pedestrian and cycling routes in conjunction with green infrastructure.
- Strengthen and expand the green corridor along the Drava River.
- Develop green corridors within the transport system.
- Implement Targeted Green Interventions such as green existing parking areas and static traffic zones, including parking lots, public transport stations, and airports.
- Explore the possibility of introducing green roofs and rainwater harvesting systems to enhance sustainability.
- Set and Apply Planning and Design Standards to help mitigate UHI (e.g. define clear standards for selecting materials that help reduce UHI).

Examples of actions:

- Implementation green roofs on the public buildings (e.g., Cultural Centre Osijek, Zrinjevac Sports Hall).
- Implementation of vertical greenery (green facades, green walls and vertical gardens)
- Implementation of rain gardens



- Renovation and landscape improvement of a central city park, applying New European Bauhaus principles (Park Zrinjevac, Oskar Nemon park)
- Green Corridors - Establishment of new tree-lined avenues and revitalization of old ones)
- Implementation of green pedestrian zones (e.g., Županijska Street), and improved cycling infrastructure (e.g., Osijek - Đakovo bike highway).
- Public Green Areas: Upgrades to green spaces at kindergartens, schools, universities, and health institutions.
- Revitalization of cultural and industrial heritage, e.g. green areas in Tvrđa
- Restoration and maintenance support for historic gardens in European Avenue and Hadrian Street

Collectively, these actions will not only mitigate the impacts of climate change but also significantly enhance the quality of life for Osijek's residents, ensuring a healthier, more sustainable urban environment for future generations.

The implementation of the strategic objectives is anticipated to have positive outcomes in building cities resilience to climate change. By expanding and enhancing the area and quality of public green spaces, the city will not only strengthen its identity as a “city of parks and gardens” but also significantly improve the urban microclimate and biodiversity. Enhanced connectivity of green infrastructure will create a cohesive network, supporting greater resilience to climate change and improving the overall quality of life for residents. These measures are expected to reduce the urban heat island effect, improve air quality, and bolster the resilience of urban infrastructure against extreme weather events. Furthermore, the integration of sustainable materials and advanced green technologies, coupled with improved water management systems such as rainwater harvesting and irrigation, will contribute to a more sustainable and adaptive urban environment. Systematic monitoring and adaptation will ensure that the city remains responsive to ongoing climate challenges, securing long-term environmental, social, and economic benefits for the community.



3.3. Strategic Development for the Courtyards in Osijek

The evaluation of potential adaptations for the courtyards within Tvrđa, together with proposed revitalization plans for pilot courtyards, is intended to advance the goals set in Osijek's Development Strategy, specifically the strategic priority A - connected, preserved, and green living space. These efforts are designed to promote green infrastructure, encourage sustainable mobility, and protect both natural and cultural heritage aligning with Special Objective 3.3, which focuses on resilience, safety, and sustainability in urban areas. In addition, such initiatives are expected to contribute to disaster risk reduction, preservation of urban natural heritage and biodiversity, and the renewal of public spaces. If implemented, the revitalization of courtyards could contribute to key outcomes anticipated by 2029, such as the creation of newly arranged public and green spaces and improved resilience to climate change and natural disasters, ultimately enhancing residents' quality of life and long-term sustainability for the city.

Furthermore, these proposed activities are closely linked to Osijek's Green Infrastructure Strategy through strategic goal B, which aims to enrich the urban environment by integrating green infrastructure elements that benefit residents' well-being. The strategy calls for revitalization of existing public green spaces such as courtyards, parks, and tree-lined avenues, and emphasizes the importance of connecting these areas with new green areas to form a cohesive and multifunctional green infrastructure network. By prioritizing connectivity and ecological integration, these courtyards could advance the city's strategic goal of fostering a greener, more liveable urban landscape. If these adaptation principles are put into practice, they could help strengthen and expand Osijek's green infrastructure network and support the city's resilience efforts.

Courtyards demonstrate the potential for climate adaptation through integration of nature-based solutions (NBS) in compact, historic urban settings.

Ecological objectives include:

- Climate adaptation: reducing urban heat islands, mitigating floods, and creating cooling microclimates.
- Water management: helping natural infiltration of rainwater and reducing pressure on the sewage system.



- Biodiversity enhancement: increasing plant diversity, establishing micro-habitats, and supporting pollinators and small animals.
- Resident well-being: providing green, shaded, and multifunctional spaces for residents.

As already described, even on a small scale (individual courtyards) these objectives align with broader city goals of expanding green and blue infrastructure, enhancing quality of life, and boosting climate resilience.



Figure 14 Proposed greening of the pilot courtyard according to the design solution

3.3.1. Main actions - strategic steps

To integrate courtyard revitalizations with the city's development vision, the following actions are proposed:

Development of Green Infrastructure



- Enhance courtyard landscapes and biodiversity by introducing diverse vegetation types, including trees, shrubs, perennials, and vertical greenery supported by freestanding or wall-adjacent structures, while respecting historic features.
- Improve the quality of green areas through removal of present invasive vegetation, improvement of soil and grassy areas and preservation of healthy mature vegetation.
- Introduce a variety of native plants and floral elements to boost biodiversity and support pollinators.
- Introduce systematic planting of trees and shrubs to increase shading and evapotranspiration.
- When revitalized, courtyards should be connected with other elements of urban green infrastructure to create a cohesive and functional urban green network of Osijek. The connection should be done with ecological corridors that are according to the Green Infrastructure Strategy of Osijek, newly planted or restored tree lines.

Support of natural infiltration and cooling

- Enhance natural infiltration by introducing new water-permeable paving or through creating additional patches of grass, infiltration strips, small rain gardens and other NBS. This will help mitigate surface runoff.
- Restore existing historic water elements and public water pipes as they help with cooling and enhance thermal comfort of courtyards and reconnect the community with their cultural heritage.
- It is recommended that sitting equipment is placed, at least partly in shade (preferably natural) to ensure usage of the courtyards during summer period.

Cultural-Heritage Sensitive Adaptation

- When integrating new elements, such as greenery, visual and spatial harmony with the historical context must be respected. Historic elements should be preserved, and the proposed design should enable a balanced coexistence of preserved historical compositions with new interventions.



- Reversible and non-invasive design techniques should be used to respect heritage regulations.
- Introduced urban equipment should be in a style aligned with the history of the courtyard and made of durable, high-quality materials. Urban equipment should be placed strategically without obstructing key views or architectural features.
- The method of conveying information should be adapted to the ambiental and historical characteristics of the space.

Social component

- Participatory approach for residents and other stakeholders should be used at each stage of design of courtyards.
- Historic courtyards should ideally serve as public spaces, emphasizing their role in enhancing urban greenery and providing accessible, pleasant communal areas for citizens.
- Neighborhood engagement should be encouraged.

Integration with Wider Urban Systems

- Linking courtyard projects with planned strategic projects within Special Objective 3.3 of the Development strategy: Resilience, Safety, and Sustainability of Urban Space and planned actions within Specific objectives B and C of the Green infrastructure development strategy - Improvement of Urban Space Quality with GI and adaptation to climate change (e.g. with restoration of Art Nouveau gardens in surrounding buildings in European Avenue and Hadrian Street).
- Establishing courtyards as nodes in a larger green infrastructure of city of Osijek serving as a link to parks, Drava river and other smaller green pockets.

3.3.2. Scope of Work and Estimated Costs

The following table presents selected and analyzed courtyards in Osijek, Croatia, with regard to the proposed scope of work and the estimated costs of potential revitalization investments. Each concept is designed to enhance urban resilience in terms of climate



change, help mitigation efforts, preserve historic value strengthen social functions, and improve the overall quality of urban space.

Planned measures include introduction of diversified greenery, improvement of rainwater management, de-sealing of impermeable surfaces, creating multifunctional public spaces, as well as adding appropriate urban furniture to foster community use. For each courtyard, the estimated revitalization cost has been calculated on the basis of its total area and a standardized cost per square meter.



Courtyard	Address	RE-PUBLIC SPACES Scope of work	Estimated revitalization cost (euro)
Pilot 1	Šetalište kardinala Franje Šepera 7A	Rainwater Management - For courtyards, rainwater management, including the feasibility of retention and infiltration needs to be analysed. Reducing impervious surfaces, introducing infiltration zones near the pipe outlets as well as small Nbs (such as rain gardens) is vital. Where necessary, improvement of slope, so that the water is directed towards designed infiltration zones is advised. Green Infrastructure & vegetation - Assessment of the condition of the trees and preservation of healthy, mature greenery. Introducing new plant species into existing green areas is advisable, as well as regularly monitoring the condition of existing trees through observation and proper care, such as appropriate crown pruning. Shrubby invasive vegetation (elderberry, fig, blackthorn) should be removed. Several young trees are planned to be implemented. Circulation & Surfaces - It is recommended that good practices continue to be used in the following revitalizations such as enhancing communication between neighbouring courtyards (as far as possible) and implementing inter-quarter openings. Infrastructure and utilities - Courtyards need to be adapted to ensure accessibility for persons with disabilities and those with mobility impairments. Barriers such as thresholds and metal obstructions at entrances should be removed and small ramps should be considered, as well as the creation of accessible pathways through the courtyards. Such surfaces should be made of stable, non-slip materials. Waste bins reflecting the Art Nouveau period should be installed. Larger containers should be placed in enclosed or screened off areas to ensure that the containers are not visually dominant. Where possible, shelters should be constructed from wood or other appropriate elements for the historic period or alternatively placed behind screening structures. In addition, planting (vertical greenery of hedges) should be incorporated around designated waste areas. Urban Furniture & Features - Sitting equipment (i.e. benches etc.) should be introduced. The shapes, colours and materials of urban equipment in courtyards should be unified, in accordance with the historic elements, e.g. for pilot courtyards, sitting equipment should be aligned with the typical design of Art Nouveau. Materials used for urban equipment should be durable and high quality. The use of plastics and other artificial materials is not allowed. Sitting equipment, where possible, should be placed to provide functionally and comfort, e.g. sitting equipment should be placed in natural shade thus enabling usage of courtyards during summer months. Placement of equipment should be in a way that key views or architectural features of the courtyard are	Yard Area: 340 m² Cost per 1 m²: 303,35 EUR Total Revitalization Cost: 103.139,00 EUR

		not obstructed. Urban equipment should support different users and should be ergonomically designed.	
Pilot 2	Šetalište kardinala Franje Šepera 7B	RE-PUBLIC SPACES Rainwater Management - For courtyards, rainwater management, including the feasibility of retention and infiltration needs to be analysed. Reducing impervious surfaces, introducing infiltration zones near the pipe outlets as well as small Nbs (such as rain gardens) is vital. Where necessary, improvement of slope, so that the water is directed towards designed infiltration zones is advised. Green Infrastructure & vegetation - Assessment of the condition of the trees and preservation of healthy, mature greenery. Introducing new plant species into existing green areas is advisable, as well as regularly monitoring the condition of existing trees through observation and proper care, such as appropriate crown pruning. Shrubby invasive vegetation (elderberry, fig, blackthorn) should be removed. Several young trees are planned to be implemented. Circulation & Surfaces - It is recommended that good practices continue to be used in the following revitalizations such as enhancing communication between neighbouring courtyards (as far as possible) and implementing inter-quarter openings. Infrastructure and utilities - Courtyards need to be adapted to ensure accessibility for persons with disabilities and those with mobility impairments. Barriers such as thresholds and metal obstructions at entrances should be removed and small ramps should be considered, as well as the creation of accessible pathways through the courtyards. Such surfaces should be made of stable, non-slip materials. Waste bins reflecting the Art Nouveau period should be installed. Larger containers should be placed in enclosed or screened off areas to ensure that the containers are not visually dominant. Where possible, shelters should be constructed from wood or other appropriate elements for the historic period or alternatively placed behind screening structures. In addition, planting (vertical greenery of hedges) should be incorporated around designated waste areas. Urban Furniture & Features - Sitting equipment (i.e. benches etc.) should be introduced. The shapes, colours and materials of urban equipment in courtyards should be unified, in accordance with the historic elements, e.g. for pilot courtyards, sitting equipment should be aligned with the typical design of Art Nouveau. Materials used for urban equipment should be durable and high quality. The use of plastics and other artificial materials is not allowed. Sitting equipment, where possible, should be placed to provide functionally and comfort, e.g. sitting equipment should be placed in natural shade thus enabling usage of courtyards during summer months. Placement of equipment should be in a way that key views or architectural features of the courtyard are not obstructed. Urban equipment should support different users and should be ergonomically designed.	Yard Area: 1630 m² Cost per 1 m²: 303,35 EUR Total Revitalization Cost: 494.460,50 EUR

 Courtyard No.1 - City hall courtyard	F. Kuhača 9	• Low and high vegetation adapted to specific microclimate should be planted and green walls in the form of evergreen clematis. • Small architectural elements creating a resident-friendly space that fosters interpersonal relationships. • Necessary demolitions should take place. • The installation of EV charging stations should be considered in a designated area. If the installation of PV systems within the courtyards is justified, priority should be given to solutions compatible with protected cultural heritage, such as invisible roof tile PV systems.	Yard Area: 570 m² Cost per 1 m²: 303,35 EUR Total Revitalization Cost: 172.909,00 EU
Courtyard No.3 - Museum of Slavonia courtyard	Josipa Bosendorfera 2	• It is required to preserve the historical elements, as indicated on the urban plan layout (General Urban plan of City of Osijek and Urban plan of Tvrđa) and specific conservation guidelines. • Greenery - planting of low and high vegetation, green walls in the form of evergreen clematis; • Small architectural elements creating a resident-friendly space that fosters interpersonal relationships; • Necessary demolitions should take place. • Good practice of hosting suitable events in Courtyard No. 2 should be preserved, and appropriate public events should be introduced in other courtyards, depending on their intended use, to encourage greater community engagement. For example, the pilot courtyards could host intimate poetry readings, small-scale mobile exhibitions, and similar low-impact activities. Larger events that require radical spatial transformations, such as the installation of an ice rink, are not permitted.	Yard Area: 772,5 m² Cost per 1 m²: 303,35 EUR Total Revitalization Cost: 234.337,87 EUR
Courtyrd No.2 - Croatian Restoration Institute courtyard	Fakultetska ulica 4	• De-sealing the courtyard by removing unnecessary solid layers, including concrete or paving stones. • Greenery - planting of low and high vegetation, green walls in the form of evergreen clematis. • Small architectural elements creating a resident-friendly space that fosters interpersonal relationships. • Necessary demolitions. • The installation of EV charging stations should be considered in a designated area. If the installation of PV systems within the courtyards is justified, priority should be given to solutions compatible with protected cultural heritage, such as invisible roof tile PV systems. • It is required to preserve the historical elements, as indicated on the urban plan layout (General Urban plan of City of Osijek and Urban plan of Tvrđa) and specific conservation guidelines.	Yard Area: 4692 m² Cost per 1 m²: 303,35 EUR Total Revitalization Cost: 1.423.318,20 EUR



3.3.3. Implementation Timeline

The revitalization of the five courtyards should follow a phased approach, aligned with the scope and estimated cost of investments defined by the Re-Public Spaces project, Development Strategy of Urban Agglomeration Osijek until 2027 and Green Infrastructure Strategy for the period from 2022 to 2032:

As the development strategy for Osijek extends to 2027, long-term predictions are challenging.

Short-term (until the end of 2026)

- Pilot implementation at Šetalište kardinala Franje Šepera 7A (pilot 1) with full monitoring of ecological and social outcomes.
- Preparation of the Guidelines for Climate Change Adaptation of Courtyard Spaces in Historic Cities and the Charter for Green and Sustainable Courtyards in Historic Cities, summarizing the Re-Public Spaces project.

Medium-term (2027-2031)

- Pilot implementation at Šetalište kardinala Franje Šepera 7B (pilot 2) with full monitoring of ecological and social outcomes.
- Analysis of the results of the revitalization of pilot 1, as well as of the Guidelines and the Charter for Courtyard Spaces in Historic Cities.
- Initial consultations and preparation of concept designs for the remaining courtyards within Tvrđa.
- Efforts to secure funding for the implementation of revitalization projects within Tvrđa (courtyard No.1, courtyard No.3)
- Public education campaigns on green infrastructure design and climate change adaptation measures.



Long-term (2030+)

- Expansion of the courtyard model to additional sites within the Historic Urban Core (courtyard No.2).
- Continuation of public education campaigns on green infrastructure design and climate change adaptation measures

3.3.3.1. Expected impacts

By aligning local courtyard revitalizations with broader city development strategies, the following synergetic impacts can be achieved:

- **Environmental:** Improved urban resilience to climate change, increased stormwater retention, reduced local flooding, reduced UHI effect, improved microclimate conditions, air quality, and enhanced urban biodiversity.
- **Social:** Multifunctional public spaces with stronger community cohesion, increased sense of ownership, better integration of sustainable mobility, and improved quality of life.
- **Educational:** Courtyards act as climate-adaptive living spaces, encouraging similar designs in other areas.
- **Economic benefits:** decreased infrastructure maintenance expenses, generation of environmentally-friendly employment opportunities, and establishment of a recognised identity as a city distinguished by its parks and gardens, positioning it as a notable tourist destination.

The revitalization of courtyards in Osijek will contribute to the city's development goals by creating more resilient, safe, and sustainable urban spaces. By improving the quality of public areas through the introduction of green infrastructure, the city will establish a wider network of green solutions and set standards for planning and design in the context of climate change mitigation and adaptation. The revitalization of pilot courtyards will serve as a model for restoring historic spaces in a climate-responsive and sustainable way.



Revitalizing the pilot courtyards will establish a model for future projects in Tvrđa, guiding subsequent investments as funds become available. These pilots will serve as test cases, allowing effective adaptation of lessons learned to other city courtyards.

4. Summary

The comprehensive analysis of courtyards in historic cities, incorporating expertise from environmental protection, climate change mitigation, heritage preservation, accessibility, and local community needs, forms the basis for developing universal revitalisation guidelines. These guidelines align with the city's key strategic documents -including the Development Strategy of Urban Agglomeration Osijek (to 2027) and the Green Infrastructure Strategy (2022-2032) to create a systematic citywide approach for adapting historic spaces.

The forthcoming Guidelines for Climate Change Adaptation of Courtyard Spaces in Historic Cities, alongside the Charter for Green and Sustainable Courtyards, will standardise and guide future courtyard revitalisations in Osijek, Croatia, and across Poland, Slovenia, and Italy. Designed for broad applicability, these resources will serve as models for Central Europe, ensuring that solutions devised for courtyards can also inform wider urban sustainability interventions.



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