ECO-ROUNDABOUTS: ASSESSING AND AMPLIFYING ENVIRONMENTAL BENEFITS IN SKOPJE'S URBAN GREEN INFRASTRUCTURE

Viktorija Brndevska Stipanović, Vlatko Andonovski
Ss. Cyril and Methodius University in Skopje, Hans Em Faculty of Forest Sciences, Landscape Architecture and Environmental Engineering, Skopje, North Macedonia

Abstract: Within the context of Skopje's urban green infrastructure, this paper investigates the environmental contributions of six strategically positioned roundabouts, called Eco-roundabouts. Emphasizing their pivotal role within the urban green infrastructure network, the study evaluates landscape design, constituent elements and the collective impact on approximately 7000 m^2 of green space. All roundabouts integrate grass cover, three of them include low vegetation and the remaining three have a combination of low and high vegetation. Noteworthy is the prevalent use of unsustainable annual flowering plants, presenting economic challenges. Ineffectual maintenance practices and plants exposure to automotive emissions further compromise optimal conditions for proper growth. The paper offers recommendations to optimize functionality, sustainability and biodiversity, addressing economic concerns and enhancing aesthetic appeal. The study advocates for a strategic and holistic approach, offering guidance to urban planners and landscape designers in maximizing the environmental benefits of Eco-roundabouts, providing their seamless integration into Skopje's resilient urban green infrastructure network.

Key words: environmental impact, North Macedonia, roundabouts, urban green infrastructure, Skopje

INTRODUCTION

Urban green infrastructure plays a vital role in enhancing the overall well-being of urban dwellers by providing a multitude of environmental and social benefits (Tzoulas et al., 2007). Roundabouts, which have gained popularity as a solution for road intersections worldwide, are increasingly recognized as essential components of urban green infrastructure.

In recent decades, there has been a notable surge in the attention devoted by researchers and practitioners to roundabout solutions. The expansive footprint of these intersections has heightened the need for focused consideration regarding ground utilization and the preservation of natural, environmental and architectural heritage (Ginelli et al., 2014).

A roundabout comprises fundamental geometric components. These include the central island situated at the heart of the roundabout, the splitter islands strategically positioned at entry points, the circular circulatory roadway and the entry (inlets) and exit (outlets) lanes (Macioszek, 2022). These elements collectively define the structural and functional aspects of a roundabout, contributing to its effectiveness in managing traffic flow.

The emphasis in this research is on the central islands of the roundabouts and their landscape design. Traditionally, the central island of roundabouts is designed and maintained as green areas, thus aligning with the goals of urban green infrastructure. The extent of their impact is contingent upon the landscape design style and the choice of constituent elements.

Roundabouts, as integral parts of urban green infrastructure, contribute to the overall improvement of environmental conditions in cities and helps to neutralize the negative impact of communication areas (Heidt, Neef, 2008). To ensure that they contribute effectively to urban green infrastructure, it is essential to approach their design and implementation from multiple perspectives. Not only should roundabouts be aesthetically pleasing, but they should also prioritize functionality (Guerrieri et al., 2015), sustainability (Breuste et al., 2015; Lombardi et al., 2012) and biodiversity (Helden, Leather, 2004; Yue, Gang, 2017). Green roundabouts must be an integral and mandatory part of green infrastructure planning, aiming to create interconnected and multifunctional networks of green spaces that provide a wide range of environmental and social benefits. It is obvious that transformation toward greener, healthier and safer management of urban mobility is needed soon. (Acuto et al., 2022).

MATERIALS AND METHODS

This paper was prepared by searching of scientific and professional literature, utilizing renowned platforms and search engines such as Google Scholar, SCIndex and Science Direct. The quest for relevant information was undertaken employing a strategic array of keywords and their synergistic combinations: roundabouts as a part of urban green infrastructure, environmental impact of roundabouts, roundabouts in Skopje, North Macedonia, roundabouts in urban areas, urban planning, street greenery, greenery and traffic system. These keywords were selected to catalyse the search process, focusing on elucidating the relationship between roundabouts and urban green infrastructure.

The literature was selected in order to present the breadth of knowledge available on the role of green roundabouts and their environmental impact as a part of urban green infrastructure. Particular emphasis was put on literature addressing the importance of roundabouts as green elements and their impact not only from aesthetic point of view, but also from the aspect of functionality, sustainability and biodiversity in urban environment.

The importance of green roundabouts was observed and presented on the example of the following roundabouts in Skopje, North Macedonia: Porta Vlae, Catholic Cathedral Sacred Heart of Jesus, Hotel Continental, Polyclinic Jane Sandanski, Avtokomanda and Polyclinic Chair.

This research aims to inventory and analyses of vegetation, a part of landscape design elements of carefully selected roundabouts in the city of Skopje, North Macedonia. All field data were collected in June 2023. The analysis addresses several different aspects (inventory of vegetation in the field, plant species selection, plant condition, their aesthetic appeal and landscape design elements according to functionality, sustainability and biodiversity). The current state of the central islands of the roundabouts is compared with the data obtained from the company Demi Engineering in Skopje, which is responsible for landscape designing and planting greenery on Roundabout Polyclinic Jane Sandanski, and also data from the archive of PE Parks and Greenery in Skopje, which is responsible for landscape designing, planting and maintenance of the rest 5 roundabouts.

Trade names of plants from the lists of PE Parks and Greenery and Demi Engineering are matched with scientific plant names using plant databases of Royal Botanic Gardens, Kew (Kew, 2023), Royal Horticultural Society (RHS, 2023) and World Flora Online (WFO, 2023). Current situation, relevant literature and documentation are analysed from the aspect of planning, designing and improving green roundabouts in urban areas like Skopje.

RESULTS

This research involves the analysis of six carefully chosen green roundabouts on the territory of the city of Skopje, North Macedonia, characterized by central islands designed and planted with vegetation. The selected Eco-roundabouts are as follows: Porta Vlae, Catholic Cathedral Sacred Heart of Jesus, Polyclinic Jane Sandanski, Hotel Continental, Avtokomanda and Polyclinic Chair (Fig. 1).

The case study focuses on the environmental impact of roundabouts in Skopje, North Macedonia, shedding light on their significance and potential for contributing to a sustainable and biodiverse urban environment.

Roundabout Porta Vlae

In May 2015, the largest roundabout in Skopje at that time was constructed at the intersection of the boulevard 'Partizanski Odredi' with the streets 'Aco Shopov' and 'Gjorce Petrov', near Porta Vlae, in the municipality of Gjorce Petrov (Fig. 2.). The central island of the roundabout was formed with diameter of 37 m. The total greenery of the central island covers an area of 1074.67 m².

The construction of this roundabout marks the completion of a network of modern traffic solutions and the resolution of another traffic bottleneck in the city. It enables easier communication for residents of municipalities Gjorce Petrov, Vlae, Karposh and all other travellers who use this route.

The initial horticultural project featured a flower-shaped design with low plants and seasonal flowers. This idea was successfully implemented and the central island has been planted with seasonal flowers, maintaining a tradition of changing the displays twice a year up until 2021.

As part of Skopje's initiative to enhance green spaces and improve air quality, there were plans to enrich the existing green areas with high-stemmed seedlings of various evergreen and deciduous species. In that period (2021), the central island of the roundabout was

Fig. 1. Location of selected roundabouts in the City of Skopje, North Macedonia

Fig. 2. Location of roundabout Porta Vlae, before and after construction

reconstructed with the creation of a new lawn and a variety of evergreen and deciduous plants, along with perennials.

A total of 205 plants of the following species were planted: *Catalpa bignonioides* 'Nana' (14), *Magnolia* × *soulangeana* (40), *Platycladus orientalis* 'Pyramidalis Aurea' (50), *Lavandula angustifolia* Mill. (82), × *Cupressocyparis leylandii* (A.B.Jacks. & Dallim.) Dallim. (14), *Fraxinus excelsior* 'Globosa' (5).

As part of the field research conducted for the preparation of this paper in July 2023 (Fig. 3), it was determined that the lavender seedlings no longer exist. There were areas covered with perennial plants *Jacobaea maritima* 'Silver Dust' (25 m²), *Coleus scutellarioides* (75 m²) and *Begonia semperflorens* Link & Otto (80 m²). *C. scutellarioides* and *B. Semperflorens*, although not seasonal, are changed as seasonal plants each growing season.

Roundabout Catholic Cathedral Sacred Heart of Jesus

This roundabout is situated in close proximity to the Catholic Cathedral Sacred Heart of Jesus in Skopje and was constructed in 2007. It features an irregular elliptical shape with the longer side measuring 38.5 m and the shorter side of 33.5 m, covering an area of 890 m².

Fig. 3. Roundabout Porta Vlae, July 2023. (Photo credit: Brndevska Stipanović V.)

Fig. 4. Roundabout Catholic Cathedral Sacred Heart of Jesus, June 2023. Photo credit: Brndevska Stipanović V.

The first horticultural arrangement was with *Chrysanthemum* L. species, arranged externally in three rows with varying colours that followed the outer line of the roundabout. The central area of the roundabout was adorned with a circle entirely filled with *Chrysanthemum* L., showcasing an array of different colours, with yellow being the dominant one.

Although chrysanthemums are perennials, they were treated as seasonal flowers. The central island of the roundabout featured seasonal flower displays that changed twice or

thrice a year. Obviously, at the end of August and the beginning of September, a total of 1320 chrysanthemums were planted, which were later replaced by 6000 violas (*Viola tricolor* L.) in mid-October. During spring, the outer circle was planted with 4000 seedlings of *Tagetes erecta* L., while the inner circle with 2000 seedlings of *Salvia splendens* Sellow ex Schult. However, in 2013, the installation of the 'Vasil Chakalarov' monument in the middle of the central island led to a reduced area for seasonal flowers within the central circle.

In 2021, a total of 50 pieces of *Photinia* × *fraseri* 'Red Robin', each with a height of 80-100 cm, were planted around the monument. As a result, the flower area around the monument was lost.

During the field research period in July 2023, the border was planted with *Tagetes erecta* (85 m²) (Fig. 4).

Roundabout Polyclinic Jane Sandanski

Constructed in March 2019, this roundabout resides in the immediate vicinity of the Jane Sandanski polyclinic within the Aerodrom municipality.

Encompassing an expanse of 706.5 m², the central island boasts a diameter measuring 30 meters. A distinct feature of this roundabout is its slightly elevated central island, which showcases a horticultural composition comprising of grass area and a selection of woody vegetation, including trees and shrubs. There are 235 plant specimens of several different species planted in this roundabout: 10 specimens of *Acer palmatum* 'Dissectum Atropurpureum' (D), 10 - of *Cupressus sempervirens* Stricta Group, 15 specimens of *Lagerstroemia indica* L. and 200 of *Juniperus* × *pfitzeriana* 'Pfitzeriana Aurea' planted in a group, which covers an area of 60 m² (Fig. 5).

Remarkably, since its inception, the plant composition and landscape design of this roundabout are unchanged. During the field research period in July 2023, it was recorded that

Fig. 5. Roundabout Polyclinic Jane Sandanski, July 2023. Photo credit: Brndevska Stipanović V.

the entire growth of evergreens is in good condition, while the deciduous plants are in a very bad condition and some of them are almost dried up.

Roundabout Hotel Continental

This roundabout was constructed during the first half of 2009. The central island of 1256 m², boasts a commanding 40-meter diameter.

In the period up until 2014, the central island's landscape was characterized by green lawn and floral compositions from annual plants. However, in 2014, a notable transformation occurred with the construction of the monument dedicated to General Mihailo Apostolski on horseback. This monument occupies a space of 25 m² at the centre of the central island. A paved path, spanning 45 m², guides observers towards this focal point. The remainder of the central island, totalling 1186 m², is covered by grass and a line of 60 m² of approximately 200 mini roses (*Rosa floribunda* Baker) with different colours, forming a border along the island's edge (Fig. 6).

Roundabout Avtokomanda

Roundabout Avtokomanda was built in June 2016 at the intersection between the streets '16 Makedonska brigada' and 'Koce Metalec'.

The central island of the roundabout was formed with an impressive diameter of 60 meters and the total greenery covers an area of 2826 m². A basket with a circular shape and a diameter of 8 meters, filled with annual flowering plants, was placed in the central part. The rest of the area was a lawn, through which annual flowering plants are also planted in different groups. The total number of flowering plants was about 10,000 pieces.

In March 2021, this roundabout was reconstructed and got a completely new look. The horticultural plan was carried out by planting a large number of woody species (trees and shrubs) on the grassy surface and also perennials in the basket. From the obtained data, but also pictures from the PE Parks and greenery archive, the variety and number of planted seedlings was great. The list contains seedlings of the following species: *Thuja occidentalis* 'Smaragd' 10 pieces, *Picea abies* Pyramidata Group 20 pieces, *Acer pseudoplatanus f. spaethii*

Fig. 6. Roundabout Hotel Continental, July 2023. Photo credit: Brndevska Stipanović V.

Fig. 7. Roundabout Avtokomanda, July, 2023. Photo credit: Brndevska Stipanović V.

Schwer. 20 pieces, *Betula pendula* 'Youngii' 20 pieces, *Nandina domestica* 'Seika'[PBR] 100 pieces, *Tilia platyphyllos* Scop. 20 pieces, *Morus latifolia 'Spirata'* 10 pieces, *Chamaecyparis lawsoniana* 'Stardust' 40 pieces, × *Cuprocyparis leylandii* 20 pieces, *Elaeagnus submacrophylla* Servett. (Ball on stem) 30 pieces, *Cupressus sempervirens* Stricta Group 20 pieces, *Acer platanoides* 'Crimson Sentry' 10 pieces, *Juniperus scopulorum* 'Skyrocket' 20 pieces, *Carpinus betulus f. pyramidalis* Dippel 30 pieces, *Jacobaea maritima* 'Silver Dust' 300 pieces.

In the period of the field research (July 2023) (Figure 7.), only some of those plants were noticed in the central island of this roundabout : *Carpinus betulus f. pyramidalis* Dippel 20 pieces, *Tilia platyphyllos* Scop. 2 pieces, *Juniperus scopulorum* 'Skyrocket' 9 pieces, *Morus latifolia* 'Spirata' 10 pieces, *Nandina domestica* 'Seika'[PBR] 97 pieces, *Betula pendula* 'Youngii' 4 pieces, *Chamaecyparis lawsoniana* 'Stardust' 3 pieces, *Elaeagnus submacrophylla* Servett. (Ball on stem) 24 pieces and *Cupressus sempervirens* Stricta Group 3 pieces. The most of them are not in good condition, some are almost dried and also, the basket is full of weeds, dried plants instead to be completely covered by *Jacobaea maritima* 'Silver Dust'.

Roundabout Polyclinic Chair

In 2020, Skopje welcomed a new roundabout situated between the municipalities of Butel and Chair. The roundabout is located at the intersection of 'Kemal Seyfula' and '2nd Macedonian Brigade' streets, adjacent to Chair Polyclinic. The central island of the roundabout covers an area of 254.34 m², with a diameter of 18 meters.

The original arrangement was with *Chrysanthemum* L. species, treated as seasonal flowers. Total 2700 pieces were planted in three interconnected spiral circles of different colour combinations. In September 2021, the chrysanthemums are substituted with a selection of evergreens, deciduous shrubs and perennial plants (Figure 8.). The following types of plants are introduced to the landscape: *Buxus sempervirens* L. (Ball) (15 pieces), *Buxus microphylla* Siebold & Zucc. (Ball) (88 pieces), *Ligustrum japonicum* Thunb. (Ball on stem) (10 pieces),

Fig. 8. Roundabout Polyclinic Chair, July 2023. Photo credit: Brndevska Stipanović V.

Syringa meyeri 'Palibin' (Ball on stem) (3 pieces), *Santolina chamaecyparissus* 'Nana' (100 pieces), *Osmanthus aquifolium* Siebold ex Siebold & Zucc. (80 pieces) and × *Cuprocyparis leylandii* 'Castlewellan' (Spiral) (3 pieces).

The side islands are also planted with *Juniperus scopularum* 'Blue Arrow' (9 pieces), *Syringa meyeri* 'Palibin' (stem ball) (10 pieces) and *Erica carnea* L. (30 pieces).

DISCUSSION

Skopje has witnessed a surge in the popularity of roundabouts over the past decade. This case study focuses on six specific roundabouts located across the city. All of these roundabouts are green spaces integrated into the urban green infrastructure network, adding approximately 7000 m² of green area (Table 1), so the implementation of these urban elements has not only increased traffic safety in the area but also revitalized the surroundings, giving the region a fresh new look. Only 2% of the total area of six roundabouts is covered by paved surface and the remaining 98% is green area (92% grass cover, 3% plant cover by perennials and woody shrubs and 3% plant cover of seasonal plants) (Fig. 9). Table 1 shows the current state of the coverage of the entire area of selected roundabouts. As Macioszek (2022) emphasizes, a fairy common practice in roundabout central island arrangements is grassing, and the similar situation is in this situation, where 6457.27 m², i.e. 92% of total area is covered by grass.

During the research period, the percentage of coverage with seasonal plants is relatively small, only 3% (Fig. 9) or 215 m² (Table 1), but as indicated in the results above, the big number of the perennials are also treated as seasonal plants. However, later in reconstructions, the use of this type of plants in some of them has been reduced, and in some, this type of vegetation is completely replaced by perennials and woody plant species (Table 2), which is commendable because their use does not fit into the politics of sustainability and poses economic challenges. These reconstructions were a part of Skopje's initiative to enhance green spaces and improve air quality, because the impact of green roundabouts on air quality is not to be neglected (Garceau, 2018).

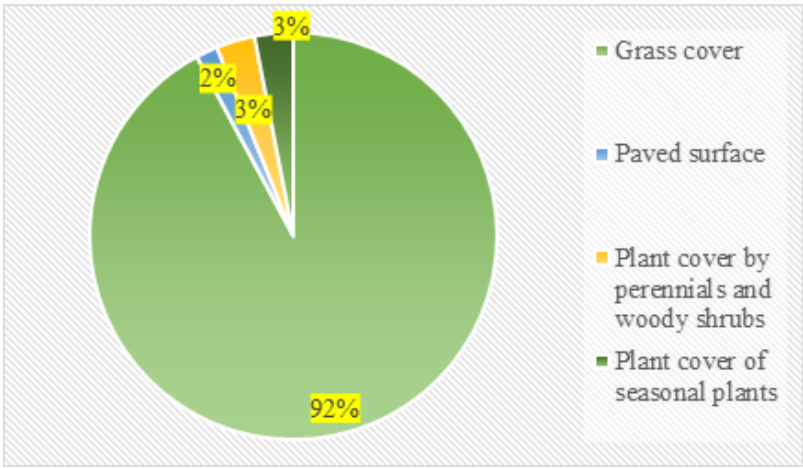

Fig. 9. Coverage of the roundabouts

Table 1. Area and coverage of selected roundabouts

		Roundabout Porta Vlae	Roundabout Catholic Cathedral Sacred Heart of Jesus	Roundabout Polyclinic Jane Sandanski	Roundabout Hotel Continental	Roundabout Avtokomanda	Roundabout Polyclinic Chair	Total (m²)
Size	Diameter (m)	37	38.5 x 33.5	30	40	60	18	
	Area (m²)	1074.67	890	706.5	1256	2826	254.34	7007.51
Grass cover (m²)		894.67	760	646.5	1126	2775.76	254.34	6457.27
Paved surface (m²)		/	50	/	70	/	/	120
Plant cover of perennials or woody creeping shrubs, hedges or plant borders of woody plants (m²)		25	20	60	60	50.24	/	215.24
Plant cover of seasonal plants (m²)		155	60	/	/	/	/	215

The first built Eco-roundabout of the six that are discussed in this paper was Catholic Cathedral Sacred Heart of Jesus, constructed in 2007, and the last one - Polyclinic Jane Sandanski, in 2019. All roundabouts except the last one built, were created with the same constituent elements, grass and seasonal plants and all of them except the Roundabout Polyclinic Jane Sandanski, later, were reconstructed (Table 2).

In terms of visibility and safety of the traffic participants, very important is what type of vegetation (low or high) is used for landscape designing of the central island at roundabouts (Pratelli, Souleyrette, 2009). Three of selected roundabouts incorporate low vegetation, and the remaining three encompass a combination of low and high vegetation (Table 3).

Table 2. Constituent elements, construction and reconstruction of roundabouts

Roundabout	Construction year	Constituent elements	Reconstruction	
Porta Vlae	May, 2015	Grass cover and seasonal plants	2021	
			Grass cover, woody plants, perennials, and reduced number of seasonal plants	
Catholic Cathedral Sacred Heart of Jesus	2007	Grass cover and seasonal plants	2013	2021
			Installation of monument, grass cover and reduced number of seasonal plants	Monument, grass cover, hedge of woody plant, and reduced number of seasonal plants
Polyclinic Jane Sandanski	March, 2019	Grass cover and woody plants	/	
Hotel Continental	2009	Grass cover and seasonal plants	2014	
			Installation of monument and border od woody plants	
Avtokomanda	June, 2016	Grass cover and seasonal plants	2021	
			Grass cover, woody plants, perennials	
Polyclinic Chair	2020	Grass cover and seasonal plants	2021	
			Grass cover, woody plants, perennials	

Table 3. Types of vegetation on roundabouts

		Roundabout Porta Vlae	Roundabout Catholic Cathedral Sacred Heart of Jesus	Roundabout Polyclinic Jane Sandanski	Roundabout Hotel Continental	Roundabout Avtokomanda	Roundabout Polyclinic Chair	Total (pieces(p.); m²)
Low vegetation	*Deciduous shrubs (p.)*	/	/	10	/		3	13 p.
	Evergreen shrubs (p.)	/	50		/	125	293	468 p.
	Evergreen trees (p.)	/	/		/		3	3 p.
	Plant cover of perennials or woody creeping shrubs, hedges or plant borders of woody plants (m²)	25	20	60	60	50.24	/	215.24 m²
	Plant cover of seasonal plants (m²)	155	60	/	/	/	/	215 m²
High vegetation	*Deciduous trees (p.)*	59	/	15	/	30	/	104 p.
	Evergreen trees (p.)	64	/	10	/	15	/	89 p.

With the further growth of vegetation, according to the choice of plant species, their arrangement and quantity, there is a serious threat in the future for obstruction of the visibility in the traffic and thus endangering the safety of the traffic participants mostly on the territory of roundabouts Porta Vlae and Avtokomanda.

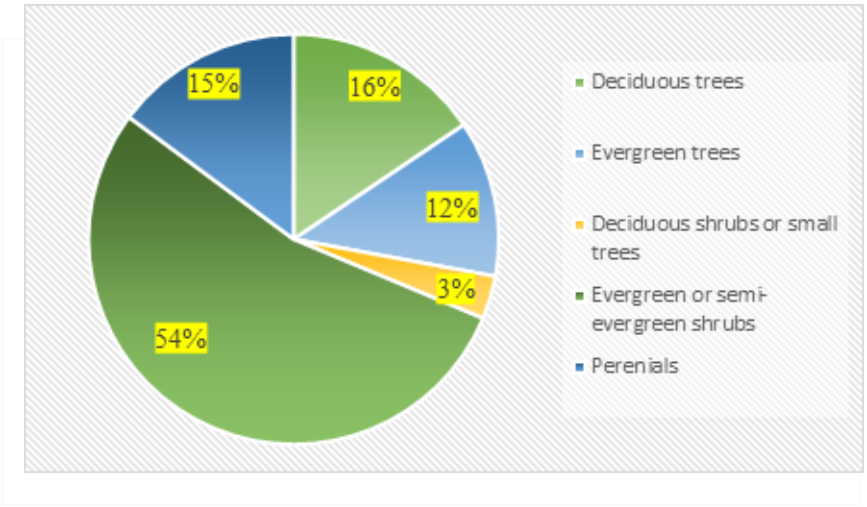

Fig. 10. Types of plants, planted individually on a grass cover

Figure 10 shows the percentage presence of different types of plants, according to the numerical status given in Table 4. So, only 28% represent high vegetation, i.e. deciduous (16%) and evergreen (12%) tree species. Certainly, not all of them pose a potential visual impediment in the future, particularly the centrally positioned evergreens with columnar form (*Cupressus sempervirens* Stricta Group), planted on the central island of the roundabout Polyclinic Jane Sandanski.

Indeed, it is an established fact that urban air and soil quality have experienced degradation in recent years, primarily attributable to the processes of urbanization, industrialization and the escalating number of vehicles, but mitigation of these negative effects can also be achieved with the help of vegetation (Nawaz et al., 2022; Kończak et al., 2021). Hence, the selection of vegetation in urban environments, particularly in close proximity to road networks, holds considerable significance (Hewitt et al., 2020; Sæbø et al., 2005), among other things, significantly affecting the reduction of air pollution (Nowak et al., 2006; Nowak et al., 2013). Green infrastructure is often mentioned as a promotional method for dealing with air pollution, where they are listed different kinds of green areas as streets and park trees, green walls and green roofs (Berardi et al., 2013). Without hesitation, the list can be expanded to include roundabouts as an integral component of contemporary green infrastructure. The introduction of vegetation into the urban landscape carries substantial significance from various perspectives, as highlighted by Beatley (2016). This is based on the premise that pollutants tend to deposit more efficiently onto vegetation compared to smoother, impervious, artificial surfaces (Hewitt, 2020). However, the selection of plant species must also be undertaken with careful consideration of their resistance to exhaust gases. This criterion is of paramount importance, especially given the location's proximity to high-frequency streets.

Certain research shows that some species are tolerant to urban conditions and have a positive effect on the improvement of the environment, such as: *Betula pendula* 'Youngii' (Kończak et al., 2021), *Carpinus betulus* and *Tilia* sp. (Tzvetkova, Kolarov, 1996), *Photinia* × *fraseri* 'Red Robin' (Mori et al., 2018), *Acer palmatum* (Bui et al., 2022; Gourdji, 2018), but some are more sensitive in that kind of conditions and become vulnerable to diseases or insects, as *Catalpa bignonioides* (Chinan, Mânzu, 2018).

Table 4. Inventory of the urban dendroflora of all roundabouts

	Scientific name of plants	Roundabout Porta Vlae	Roundabout Catholic Cathedral Sacred Heart of Jesus	Roundabout Polyclinic Jane Sandanski	Roundabout Hotel Continental	Roundabout Avtokomanda	Roundabout Polyclinic Chair	Total (pieces (p.)/m²)
Deciduous trees	*Betula pendula* 'Youngii'					4		4 p.
	Catalpa bignonioides 'Nana'	14						14 p.
	Carpinus betulus f. pyramidalis Dippel					20		20 p.
	Fraxinus excelsior 'Globosa'	5						5 p.
	Lagerstroemia indica L.			10				10 p.
	Magnolia × soulangeana	40						40 p.
	Morus latifolia 'Spirata'					10		10 p.
	Tilia platyphyllos Scop.					2		2 p.
Evergreen trees	*Chamaecyparis lawsoniana* 'Stardust'					3		3 p.
	Cupressus sempervirens Stricta Group			10		3		13 p.
	× *Cupressocyparis leylandii* (A.B.Jacks. & Dallim.) Dallim.	14						14 p.
	× *Cuprocyparis leylandii* 'Castlewellan' (Spiral)						3	3 p.
	Platycladus orientalis 'Pyramidalis Aurea'	50						50 p.
Deciduous shrubs or small trees	*Acer palmatum* 'Dissectum Atropurpureum' (D)			10				10 p.
	Rosa floribunda Baker				60 m²			60 m²
	Syringa meyeri 'Palibin' (Ball on stem)						3	3 p.
	Ligustrum japonicum Thunb. (Ball on stem)						10	10 p.
Evergreen or semi-evergreen shrubs	*Nandina domestica* 'Seika'[PBR]					97		97 p.
	Buxus microphylla Siebold & Zucc. (Ball)						88	88 p.
	Buxus sempervirens L. (Ball)						15	15 p.
	Elaeagnus submacrophylla Servett. (Ball on stem)					24		24 p.
	Juniperus × *pfitzeriana* 'Pfitzeriana Aurea'			60 m²				60 m²
	Juniperus scopulorum 'Skyrocket'					9		9 p.
	Osmanthus aquifolium Siebold ex Siebold & Zucc.						80	80 p.
	Photinia × *fraseri* 'Red Robin'		50					50 p.
Perennials	*Jacobaea maritima* 'Silver Dust'	25 m²				50.24 m²		75.24 m²
	Santolina chamaecyparissus 'Nana'						100	100 p.
Seasonal plants	*Begonia semperflorens* Link & Otto	80 m²						80 m²
	Coleus scutellarioides	75 m²						75 m²
	Tagetes erecta L.		85 m²					85 m²

In any case, of all specified information and data, and also from the conclusions of the field research, the reason for the rather poor condition, especially of the plants at certain roundabouts, such as Avtokomanda and Porta Vlae, is not based only on the choice of vegetation, but much more on the irregular and inadequate maintenance of the green areas at all.

Table 4 shows a comprehensive list of all plant species that are part of the vegetation of the central islands of six selected roundabouts.

The commendable practice of constructing roundabouts in the city of Skopje is particularly noteworthy, especially in the context of green or Eco-roundabouts. Beyond their fundamental traffic management functions, roundabouts, with appropriately designed central island arrangements, can also serve the purpose of organizing the architecture of the local area (Macioszek, 2022). That kind of transformation of urban spaces in Skopje, not only elevates the visual appeal of the surroundings but also contributes to the overall well-being of the environment, providing a sustainable and enriching habitat for various flora and fauna to thrive, while greatly increased traffic safety in the territory of the city.

CONCLUSIONS

The case study of roundabouts in the city of Skopje, North Macedonia, emphasizes their significance as green spaces within the urban green infrastructure network.

All six researched roundabouts (Porta Vlae, Catholic Cathedral Sacred Heart of Jesus, Polyclinic Jane Sandanski, Hotel Continental, Avtokomanda and Polyclinic Chair) are integrated into the urban green infrastructure network, contributing approximately 7000 m^2 of green area.

Only 2% of the total area of six roundabouts is covered by paved surface and the remaining 98% is green area (92% grass cover, 3% plant cover by perennials and woody shrubs and 3% plant cover of seasonal plants), which is the reason why we call them Eco-roundabouts.

It is striking that 92% of total area is covered by grass. Grass cover is present in all roundabouts, three roundabouts incorporate low vegetation and the remaining three feature a combination of low and high vegetation. The visibility and safety of traffic participants are significantly influenced by the type of vegetation, whether low or high, used in the landscape design of the central island at roundabouts. The future threat of obstruction to visibility in traffic, and consequently the endangerment of traffic participants, becomes a serious concern with the continued growth of vegetation. This risk is particularly pronounced in the areas of roundabouts Porta Vlae and Avtokomanda, depending on the choice of plant species, their arrangement and quantity.

The first roundabout, constructed in 2007, was Catholic Cathedral Sacred Heart of Jesus, and the last one was Polyclinic Jane Sandanski, built in 2019. All roundabouts except the last one, built later, were reconstructed.

All roundabouts except Polyclinic Jane Sandanski, were created with the same constituent elements, grass and seasonal plants. With the reconstruction of 4 roundabouts (Porta Vlae, Catholic Cathedral Sacred Heart of Jesus, Avtokomanda and Polyclinic Chair) in 2021, the landscape design has been changed and the use of seasonal plants has been reduced or excluded, which is commendable because their use does not fit into the politics of sustainability and poses economic challenges. The negative thing is that the big number of the perennials is also treated as seasonal plants.

The inventory of the urban dendroflora of all six roundabouts shows 30 different taxa, and most of them (54%) are evergreen or semi-evergreen shrubs.

The suboptimal conditions experienced by many plants can be attributed to a combination of inadequate maintenance practices and poor plant selection, especially in terms of resistance to harmful automotive emissions. The visibly poor condition of vegetation, as evidenced by examples, such as roundabouts Avtokomanda and Porta Vlae, serves as a clear illustration of the detrimental effects arising from irregular and insufficient maintenance practices on roundabouts.

Eco-roundabouts in the city of Skopje are, and must be, an integral and mandatory part of green infrastructure planning, aiming to create interconnected and multifunctional networks of green spaces that provide a wide range of environmental and social benefits, but improvements are necessary to maximize their environmental impact.

Recommendations are given to optimize the functionality, sustainability and biodiversity of roundabouts, while maintaining aesthetic appeal by changing today's landscape design practices. Creating rain gardens into the area of central islands of roundabouts or designing xeri-gardens can greatly improve Eco-roundabouts in the terms of functionality, sustainability and biodiversity. Plant species should be carefully selected to ensure they do not negatively impact the visual experience for traffic participants.

So, by adopting a strategic and holistic approach, urban planners and landscape designers can optimize the functionality, sustainability and biodiversity of Eco-roundabouts, ensuring their integration into a cohesive and resilient urban green infrastructure network.

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E-mail: vbstipanovic@sf.ukim.edu.mk