International Design Practices for Roundabouts

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Abstract. Roundabouts are a special form of junction, which has been widely implemented during the last years, since for specific cases they are considered a suitable solution, in terms of safety and capacity, compared to conventional intersection types. Different types of roundabouts exist, and the design of each type follows specific principles, for reaching their design potential and avoiding negative implications. Although the roundabout types are common among several countries, the design principles and guidelines vary. This paper reviews the guidelines of six major countries (i.e., the United Kingdom, France, Germany, the Netherlands, the United States and Australia), which are considered front-runners in the design of roundabouts. For each national guideline, the main goal, the field of application and the estimation of basic roundabout geometric elements are identified. Through the comparison of national guidelines, points of convergence and divergence are identified and discussed. Recognizing these points can be a useful guidance for the development of guidelines for other countries, by identifying and transferring elements that best fit their road conditions.

Keywords: Roundabout · Geometric characteristics · Guidelines · Design elements

1 Introduction

The roundabout is an intersection type that is mainly used in urban areas. Its application in modern road design dates back to the 20th century; however, in the 1950s, it was abandoned due to increased traffic and congestion, use of traffic signals, and increased number of road accidents. Traffic congestion was radically addressed in the UK in 1966 with the provision of right-of way to circulating vehicles. This regulation resulted in the systematic study for implementing roundabouts, which showed that without the use of traffic signals a sufficient degree of road safety and capacity could be achieved.

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The type of intersection that will be selected and applied is evaluated by weighting criteria, including road safety, capacity (level of service), environment, economy, and social acceptance (Tollazzi et al. 2015). However, the roundabout design is not a standard process that is followed by all countries, since roundabout involves choosing between trade-offs of safety and capacity criteria. Smooth traffic flow conditions are achieved when the traffic volumes all evenly distributed to all converging roads. Increasing the number of entry, exit and circulatory lanes to improve capacity results to increases vehicle speeds and lower safety levels.

The roundabouts provide better safety compared to conventional intersections, where traffic is regulated by traffic signals, as the number of possible vehicle conflict points is significantly lower (Wu and Brilon 2017; Giuffre et al. 2018). Conflict points are locations in or on the approaches to an intersection where vehicles paths merge, diverge, or cross. Pedestrian and bicycle crossings are also facilitated, because shorter crossing lengths are required, while at the same time vehicle speeds are lower (Campisi et al. 2020; Gruden et al. 2022). Although their advantages, the design elements of the roundabouts may limit their application in a road network. The circular movement of heavy vehicles usually becomes a challenge for transportation engineers, especially on urban roads with a significant number of buses.

Following the selection of a roundabout as the optimal intersection type, the geometric elements are designed. The approaching leg axes are laid and the entry/exit lanes, the circulatory roadway and the central island are calculated. The roundabout design usually requires three performance checks: 1) The examination of the design vehicle swept path, 2) the fastest path analysis, and 3) the visibility checks. If these checks do not agree with the design guidelines, the geometry of the elements is modified (Ahac et al. 2021). Several countries at global level have developed technical guidelines for the design, dimensioning and operation of roundabouts, which evolved over time. To review and compare existing practices on roundabout design, six countries are selected among different continents, in Europe (i.e., United Kingdom, France, Germany, the Netherlands), in North America (the United States of America) and in Australia/Oceania (Australia). These countries are selected because they use similar design elements for roundabouts (i.e., the inscribed circle diameter, the circulatory roadway, the apron, the splitter island, and the entry and exit leg design) and also because they are considered front-runners in roundabout design.

The technical guidelines that are reviewed in this study aim to determine the scope of roundabout application in the road network and then provide the optimum design for road safety and capacity. The identified differences between the various national guidelines mainly concern the way these problems are approached.

2 Roundabout Design

The first technical guideline for roundabouts was introduced in the UK in 1993, whereas the second one was released by Australia the same year. In European countries, the formation of technical instructions for roundabouts started in France in 1998, and in Germany and Switzerland in 1999. In 2000, a manual with instructions for designing and evaluating the performance of roundabouts was published in the US, based largely on the experience of Australia, the United Kingdom, France, and Germany. The roundabout design

requires a considerable amount of iteration among geometric layout, operational analysis, and safety evaluation (Federal Highway Administration 2011). Therefore, variations in the design guidelines for roundabouts and emphasis on the estimation of geometric elements' values are presented in the following sections for six major countries: the UK, France, Germany, the Netherlands, the US and Australia.

2.1 United Kingdom

Design Principles

In the UK, the design guideline (The Highways Agency 2007; Highways England 2020) aims to minimize vehicle delays while maintaining safety for all intersection users. Therefore, attributes such as the traffic flow, speed, and the intersection site, are considered for the estimation of geometric elements. Two important elements are: the deflection of the route in the entry lane of the roundabout to ensure safety, and the width of the entry lane and its angle relative to the roundabout to ensure traffic performance. Nevertheless, the guideline recommends that a maximum number of three lanes could be used for the entry legs and the circulatory roadway. Finally, it is allowed to design roundabouts without a circular central island and a stable number of traffic lanes in the circulatory roadway.

Roundabout Types

According to the UK road and bridge design instruction manual (The Highways Agency 2007; Highways England 2020), roundabouts are classified into the following five types: a) Regular roundabouts, b) Single-lane roundabouts, c) Mini roundabouts, d) Roundabouts with traffic lights, e) Double roundabouts.

It is pointed out that in continental European countries the roundabouts with traffic lights are not considered as roundabouts, because priority is determined by traffic lights. Table 1 summarizes the basic geometric elements for the design of roundabouts in UK.

Regular Roundabouts. They are applied in the following cases:

- On roads with a permitted speed of more than 50 mph and an average daily traffic of more than 8,000 vehicles/day per converging road.
- On roads with a permitted speed of less than 40 mph and an average daily traffic of more than 12,000 vehicles/day per converging road.

The number of lanes in the entry/exit routes varies; however, it is intended to provide 2 or even 3 entry/exit lanes to increase the roundabout capacity. Regular roundabouts are designed with a maximum number of 4 legs, since more legs result to increased inscribed circle diameter and higher vehicle speeds. The following guideline applies for designing the basic geometric elements of regular roundabouts:

- The inscribed circle diameter has a value of at least 28 m, and max 100 m.
- The width of the circulatory roadway is estimated as 1.0 to 1.2 times the wider entry width, but it is recommended not to exceed 15 m. This width does not include the width of the mountable apron around the central island.

- The central island has a diameter of at least 4 m.
- The width of a single-lane entry ranges between 3.0 and 4.5 m.; for multiple lanes entries the width ranges between 3.0 and 3.5 m. for each lane. The entry radius ranges between 10 and 100 m.
- The exit width for single-lane roundabout ranges between 7.0 and 7.5 m. For two-lanes exits the width ranges between 10.0 and 11.0 m. The exit radius ranges between 20 and 100 m., but a radius of 40 m. is recommended.

Single-Lane Roundabout. Single-lane roundabouts are applied for single-lane converging roads, with:

- A permitted speed of more than 50 mph and a maximum average daily traffic of 8,000 vehicles/day per converging road.
- A permitted speed of less than 40 mph and a maximum average daily traffic of 8,000 vehicles/day per converging road.

The size of the central island for single-lane roundabouts is similar to the one applied for regular roundabouts. However, due to single lane entries and exits, the single-lane roundabouts allow the application of lower entry/exit radius; thus, resulting in greater route deflection for incoming vehicles and safer pedestrian and bicycle crossings. The following applies to the basic geometric elements for single-lane roundabouts:

- The inscribed circle diameter ranges from 28 to 36 m.
- The width of the circulatory roadway is estimated as 1.0–1.2 times the wider entry width, but it is recommended not to exceed 6.0 m.
- The circular island has a diameter of at least 4.0 m.
- The width of the island apron (if required) depends on the inscribed circle diameter and the central island diameter.
- The entry radius ranges between 10 and 100 m., but a minimum radius of 20 m. is recommended if heavy vehicles use the roundabout.
- The exit width is similar to the entry width; a value of 4.5 m. is recommended while the exit radius ranges between 15 and 20 m.

Mini Roundabouts. They operate similar to a regular roundabout; however, their central island (the diameter ranges between 1.0–4.0 m.) is completely mountable. They are not used if more than four roads converge in urban areas and all entry/exit routes have only one lane. The permitted speed limit for all legs is set to 30 mph. They are primarily used to achieve speed reduction for passenger vehicles; however, due to their geometric elements, they are not recommended for:

- Separated roads
- Roads serving buses and heavy vehicles
- Roads serving U-turns

- Intersections, with converging roads with: 1) a maximum average traffic volume of 500 vehicles/day, or 2) a total peak load of less than 500 vehicles/hour.

Roundabouts with Traffic Signals. For roundabouts with high traffic volumes, it is possible to install traffic signals in one or more legs, or/and at the respective intersecting points of the circulatory roadway. Such conditions may allow the implementation of different types of intersection, which depends on the width of the roads, traffic volumes and the coordination of traffic lights.

Double Roundabouts. The design of each roundabout in a double roundabout layout, may be regular, single-lane or mini. The two roundabouts are connected by a road section, with a width that depends on the traffic volume between them. Double roundabouts are mainly applied:

- When more than four roads converge
- When all roads do not converge at the same location
- To connect two parallel roads, separated by an obstacle (e.g., highway, river).

Table 1. Roundabout types and basic geometric elements in the UK.

Geometric element	Roundabout type		
	Regular	Single-lane	Mini
Inscribed circle diameter [m]	28.00–100.0	28.00–36.00	≤28.00
Circulatory roadway width [m][1]	≤15.00	≤6.00	n.a
Diameter of central island [m]	≥4.00	≥4.00	1.00–4.00 (mountable)
Entry width [m]	3.00–4.50	3.00–4.50	n.a
	3.00–3.50 per lane		
Entry radius [m]	10.00–100.00	n.a	3.00–4.00
Exit width [m]	7.00–7.50	4.50	n.a
	10.00–11.00[2]		
Exit radius [m]	20.00–100.0	15.00–20.00	n.a

[1]The width is estimated as 1.00–1.20 times the wider entry width. [2] Refers to two-lanes exits

2.2 France

Design principles
The design of roundabouts in France started in 1984 and the national guideline is divided into urban and rural design (Service d'Études Techniques des Routes et Autoroutes 1998; CERTU 2010). The basic principles governing the roundabouts' design according to the French guidelines are:

- A maximum number of 6 routes are allowed to converge to the intersection. The angles between the entry/ exit legs on the perimeter of the circulatory roadway should be evenly distributed.
- For a single-lane roundabout an inscribed circle diameter of 15 m. is considered satisfactory, as it ensures a smooth traffic flow and facilitates the pedestrians and bicycles crossings. In areas with negligible traffic volumes, the diameter may be reduced up to 12 m. For two-lanes a diameter of 25 m. is acceptable.
- The central island of the roundabout has a circular shape. The axes of the legs should go through, as close as possible, the center of the island. The value of radius for entry, circular routing, exit routes depends on the radius of the inscribed circle, and should not exceed 100 m.
- The exits have only one lane; using a second lane is justified only in case of high traffic volumes.
- The entry and exit legs are separated by splitter islands. Replacement of islands with road markings is only allowed at minor roundabouts.

According to the French guidelines three types of urban roundabouts are recommended:

Mini Roundabout. They have been implemented since late 1980s. The central island is completely mountable with a diameter ranging between 3.0 and 5.0 m.

Single-Lane Roundabout. It is the typical form of roundabout that is used on urban roads with increased traffic volume. All entries and exits are designed as a single-lane routes. The central island is surrounded by a mountable road strip 1.0–2.0 m. wide, while the splitter islands are 2.0 m. wide, to provide safe pedestrian crossings.

Medium and Large Roundabouts. They are used when at least one of the converging roads has more than one lane or when more than four roads converge. Two lanes are used for the exit route, if the peak traffic volume exceeds 1,200 vehicles/hour. Table 2 provides the basic geometric features of urban roundabouts.

Roundabouts that are located on rural roads vary according to the value of the inscribed circle radius. The following recommendations apply for selecting the appropriate radius:

- National and provincial roads without median: On the main interurban road the value of the inscribed circle radius ranges between 15 and 25 m., to facilitate trespassing of heavy vehicles. A radius of 20 m. is preferred for three-lanes roads, whereas a radius between 20 and 25 m. is used for intersections with more than four legs.

Table 2. Types and basic geometric characteristics for urban roundabouts in France.

Geometric element	Roundabout type		
	Mini	Single-lane	Medium and large
Inscribed circle diameter [m]	7.50–12.00	12.00–15.00	>15.00
Circulatory roadway width [m]	6.00–9.50	≥6.00	7.20–8.40
Width of mountable island [m]	n.a	1.00–2.00	n.a
Central island radius [m]	1.50–2.50 (mountable)	n.a	n.a
Entry width [m]	2.50–3.50	3.00–3.50	6.00–7.00
Entry radius [m]	n.a	8.00–15.00	n.a
Exit width [m]	2.75–3.50	≥3.50	≥7.00
Exit radius [m]	n.a	15.00–20.00	n.a

- National and provincial divided roads: As a general rule, a radius of 25 m. is selected.
- Local interurban roads: If traffic of heavy vehicles is negligible, a radius between 12–15 m. is applied.

The value of the inscribed circle radius defines the rest of the design elements as shown in Table 3.

Table 3. Types and basic geometric characteristics for rural roundabouts in France.

Geometric element	Thresholds	Usual values [m]			
Inscribed circle radius Rg	12 m–25 m	Rg = 12	Rg = 15	Rg = 20	Rg = 25
Circulatory roadway width la	6.00 m–9.00 m	7.00	7.00	7.00	8.00
Width of mountable island slf	1.50 m–2.00 m	1.50	1.50	n.a	n.a
Central island radius Ri	Rgxlaxslf	3.50	6.50	13.00	18.00
Entry width le	4.00 m	4.00	4.00	4.00	4.00
	2 × 3.50 m	2 × 3.50	2 × 3.50	2 × 3.50	2 × 3.50
Entry radius Re	10.00 m–15.00 m και Re≤Rg	12.00	15.00	15.00	15.00
Exit width ls	4.00 m–5.00 m	4.00	4.00	4.50	5.00
	2 × 3.50 m	2 × 3.50	2 × 3.50	2 × 3.50	2 × 3.50
Exit radius Rs	15.00 m–30.00 m και Rs>Ri	15.00	20.00	20.00	20.00
Route diverging radius Rr	Rr = 4 × 0Rg	48	60	80	100
Median width	≥2.00 m	≥2.00	≥2.00	≥2.00	≥2.00

2.3 Germany

Design Principles
The German guidelines places particular emphasis on road safety compared to capacity. Thus, the roundabout design is governed by the following basic principles (Forschungsgesellschaft für Straßen- und Verkehrswesen 1998; Forschungsgesellschaft für Straßen- und Verkehrswesen 2006):

- The circular island should achieve speed reduction due to its configuration.
- The entry and exit legs are designed as perpendicular as possible to the central island (i.e., their axes pass as close as possible to the center of the circle). Sharp angled legs are not allowed to converge with the roundabout as they would enable high vehicle speeds.
- All entries and exits are designed as single-lane routes. Two-lanes entries/exits are allowed for larger diameter roundabouts.
- Road pavement markings are avoided as they encourage the parallel movement of vehicles in the roundabout (even for roundabouts with a large circulatory roadway width).

Roundabouts are implemented in urban and interurban areas, at intersections with high number of road accidents and at intersections that are controlled by traffic signals and long waiting time are recorded on the main arterial road. On the contrary, roundabouts are avoided on roads with high traffic volumes, increased pedestrian and bicycle traffic and on city bus-routes.

Roundabout Types
Mini Roundabouts. They are implemented exclusively on urban roads for a maximum traffic volume of up to 12,000 vehicles/day. In special cases the capacity may reach 18,000 vehicles/day; in such cases the traffic volumes are uniformly distributed on entry legs and the number of left movements is low. Experiments with rural mini-roundabouts have also been performed. Results showed that mini-roundabouts are not recommended outside built-up areas due to safety concerns (Brilon 2011).

Roundabouts with Small Diameter – Urban Roads. They are applied on urban roads with a maximum traffic volume of 25,000 vehicles/day. However, when traffic exceeds 15,000 vehicles/day, the level of service depends on the distribution of traffic on individual legs. A mountable central island is used to facilitate the movement of heavy vehicles. A splitter island is used between entry/exit legs to ensure the safe crossing of pedestrians and bicycles. For pedestrians and cars this type of roundabout seems to be the safest type among all types of intersections (Meewes 2003).

Roundabouts with Small Diameter – Interurban Roads. They are applied on interurban roads without using a mountable central island. Their capacity is similar to urban roundabouts. A splitter island is used between entry/exit legs to ensure the safe crossing of pedestrians and bicycles.

Large Roundabouts. They are rarely used on urban and interurban roads, due to their lower road safety level compared to other types. Their capacity reaches 32,000 vehicles/day regardless of the distribution of the traffic volume on individual legs. The design of entries as two-lane routes is allowed.

Special Types of Roundabouts. The German guidelines also provide directions for designing exclusive lanes for the direct connection of two adjacent legs (i.e., right turns). In such cases, and if the required area is available, the additional right-hand lanes are considered particularly beneficial, as they prevent the design of a second lane in the entry leg. In special cases the central island may be also designed as a spiral node (i.e., turbo roundabouts), which were developed and implemented mainly in the Netherlands. Table 4 summarizes the basic geometric characteristics for roundabouts in Germany.

Table 4. Types and basic geometric characteristics for roundabouts in Germany.

Geometric element	Roundabout type				
	Mini roundabout	Small diameter – Urban roads	Small diameter – Interurban roads	Large roundabouts	
				Urban roads	Interurban roads
Maximum daily traffic [vehicles/day]	12,000 (18,000)*	25,000	25,000	32,000	32,000
Inscribed circle radius D [m]	13.00–22.00	26.00–40.00	30.00–50.00	40.00–60.00	45.00–60.00
Circulatory roadway width B_K (with mountable central island) [m]	4.00–6.00	6.50–8.00	6.50–7.50	8.00–10.00	8.00–10.00
Ratio roadway to mountable central island	Mountable central island	3:1	Without mountable central island		
Entry width B_Z [m]	3.25–3.75	3.25–3.75	3.50–4.00	3.25–3.75	3.50–4.00
				2 x 3.25	2 x (3.25–3.50)
Exit width B_A [m]	3.50–4.00	3.50–4.00	3.75–4.50	3.50–4.00	3.75–4.50

(*continued*)

Table 4. (*continued*)

Geometric element	Roundabout type				
	Mini roundabout	Small diameter – Urban roads	Small diameter – Interurban roads	Large roundabouts	
				Urban roads	Interurban roads
Entry radius R_Z [m]	8.00–10.00	10.00–14.00	14.00–16.00	12.00–16.00	16.00–20.00
Exit radius R_A [m]	8.00–10.00	12.00–16.00	16.00–18.00	14.00–16.00	16.00–20.00
Width of island between entry and exit legs B_F [m]	n.a	1.60–2.50	1.60–2.50	1.60–2.50	1.60–2.50

*The values in brackets refer to conditions that traffic flow is uniformly distributed.

2.4 The Netherlands

For selecting the optimum intersection type in the Netherlands, three criteria are considered important, the intersecting roads' classification, capacity, and road safety. The most important criterion is the roads' functional classification. Roundabouts are designed when collector roads converge or when a collector and an access road intersect (in such case the conventional priority intersection is preferred, followed by the roundabout) (Royal Haskoning 2009). A single-lane roundabout may serve an average daily traffic volume of 25,000 vehicles/day. For higher traffic volumes, the following recommendations are provided (Royal Haskoning 2009):

- Integration of an additional lane that provides exclusive right-turns for adjacent legs.
- Widening of the circulatory roadway width (i.e., two traffic-lanes), while the entry and exit lanes maintain a single lane, (capacity up to 30,000 vehicles/day).
- Widening of the circulatory roadway width (i.e., two traffic-lanes) and use of two-lanes for entry and exit legs (capacity up to 40,000 vehicles/day).
- Development of a spiral circular intersection (turbo).

The Netherlands applies mostly the first and the last recommendation. On the contrary, the implementation of two-lane roundabouts has been abolished, because performance in terms of safety and capacity have been disappointing. Existing nodes of this shape are gradually transformed into spiral circular nodes. Tables 5 and 6 summarize the basic geometric characteristics for single-lane and two-lane roundabouts, respectively, in the Netherlands.

Table 5. Types and basic geometric characteristics for single-lane roundabouts in the Netherlands.

Geometric element	Design vehicle		
	Typical vehicle (Length 15.50m)	Vehicle length 22.00m	Vehicle length 27.00m
Inscribed circle radius R_{bu} [m]	18.00	18.00	18.00
Central island radius R_{bi} [m]	12.75	12.75	12.75
Circulatory roadway width B [m]	5.25	5.25	5.25
Width of mountable central island [m]	1.50	3.00	4.00
Entry width B_t [m]	3.50–4.00	4.00	4.00
Exit width B_a [m]	4.00- 4.50	4.50	4.50
Entry radius R_t [m]	8.00–12.00	12.00	12.00
Exit radius R_a [m]	12.00–15.00	15.00	15.00
Width of island between entry and exit legs B_m [m]	3.00	3.00	3.00
Length of island between entry and exit legs L_m [m]	10.00–15.00	10.00–15.00	10.00–15.00

Table 6. Types and basic geometric characteristics for two lanes roundabouts the Netherlands.

Geometric element	Values				
Inscribed circle radius R_{bu} [m]	20.00	25.00	29.00	33.50	38.00
Central island radius R_{bi} [m]	10.00	16.00	20.00	25.00	30.00
Circulatory roadway width B [m]	10.00	9.00	9.00	8.50	8.00
Entry width [m]	3.50–4.00	3.50–4.00	3.50–4.00	3.50–4.00	3.50–4.00
Entry width 2-lanes [m]	Width varies				
Exit width [m]	4.00–4.50	4.00–4.50	4.00–4.50	4.00–4.50	4.00–4.50
Exit width 2-lanes[m]	Width varies				
Entry radius R_t [m]	12.00	12.00	12.00	12.00	12.00
Exit radius R_a [m]	15.00	15.00	15.00	15.00	15.00

2.5 United States of America

Design Principles

Emphasis is placed on the geometric elements that aim to achieve speed reduction to vehicles entering a roundabout. This is achieved by using route diversions and providing narrow cross-sections, which in turn negatively affect the roundabout's capacity.

It is advisable that the axis of the approaching legs should be aligned as close as possible to the center of the roundabout circle. Crossing the center, to the left of the center is acceptable. However, crossing to the right of the center should be avoided as it encourages higher entry speeds.

At roundabouts all converging roads are treated equally; vehicles entering the roundabout must give priority to those moving on the roundabout. For this reason, the US guideline recommends that the design of the roundabouts should take into account the roads' functional classification, but it does not provide specific directions for selecting a roundabout (Federal Highway Administration 2000; Federal Highway Administration 2011; Transportation Research Board 2016).

Roundabout Types

Mini Roundabout. They are implemented at urban intersections with a maximum traffic volume of 10,000 vehicles/day and a maximum vehicle speed of 25 km/h. The design is mainly based on the German experience.

Urban Compact Roundabouts. They are implemented at urban intersections with a maximum traffic volume of 15,000 vehicles/day and a maximum vehicle speed of 25 km/h. Their design is based mainly on the German experience. The main features include a mountable circular apron around the central island, the splitter island between entry/exit legs, and a single-lane entry/exit.

Urban Single-Lane Roundabouts. They are implemented in urban intersections with significant traffic of up to 20,000 vehicles/day. The desired maximum entry speed is 35 km/h. They differ from the urban compact roundabouts, as their diameter is larger. The main features are the mountable circular apron around the central island and the splitter island between entry/exit legs. Their design has been influenced by the respective guidelines of Australia, France and the United Kingdom.

Urban 2-Lanes Roundabouts. At urban intersections, where at least one entry road occupies two lanes, the diameter is widened to allow two vehicles to move simultaneously. The entry speed should not exceed 40 km/h. This type is similar to the urban single-lane roundabout; however, a mountable apron is not used. Their design has been primarily influenced by the respective guidelines of the United Kingdom, and secondarily by Australia and France.

Interurban Single-Lane Roundabouts. They are similar to urban single-lane roundabouts. They are selected for a maximum traffic volume of 20,000 vehicles/day. However, they differ from the urban single-lane roundabout, as they may have a larger diameter, they lack a mountable central apron and their exits are more tangential to the roundabout circle. The desired maximum entry speed is 40 km/h. Their design is based on the respective guidelines of Australia, France and the United Kingdom.

Interurban 2-Lanes Roundabouts. At interurban intersections, where at least one entry occupies two lanes, the diameter is widened to allow two vehicles to move simultaneously. They are designed similarly to urban two-lanes roundabouts. Differences include: the exits are designed more tangential to the circle to increase the exit speed of vehicles due to the reduced pedestrian and bicycle volumes; the entry speed should not exceed 50 km/h. Their design is based on the methods used mainly in the United Kingdom and secondarily in Australia and France.

Table 7 summarizes the geometric elements for various types of roundabouts in the United States.

Table 7. Roundabout types and basic geometric characteristics in the US.

Geometric element	Roundabout type					
	Mini	Urban compact	Urban single lane	Urban 2-lanes	Interurban single lane	Interurban 2-lanes
Maximum daily traffic [vehicles/day]	10,000	15,000	20,000	45,000 (estimation is required)	20,000	45,000 (estimation is required)
Inscribed circle radius [m]	13.00–25.00	25.00–30.00	30.00–40.00	45.00–55.00	35.00–40.00	55.00–60.00
Circulatory roadway width (without mountable island)[a] [m]	≥5.00	≥5.00	≥5.00	≥9.10	≥5.00	≥9.10
Width of mountable central island	Mountable central island	1.00–4.00	1.00–4.00	n.a	(1.00–4.00)	n.a
Entry width [m]	n.a	4.30–4.90	4.30–4.90	≥6.00	4.30–4.90	≥6.00
Entry radius[2] [m]	n.a	10.00–30.00	10.00–30.00	uniform 30–60	10.00–30.00	uniform 40–80
				Two consecutives		Two consecutives
Exit radius[2] [m]	10.00–12.00	10.00–12.00	>15.00	n.a	>15.00	n.a
Width of island between entry and exit legs [m]	n.a	>1.80	>1.80	>1.80	>1.80	>1.80

[a]The circulatory roadway width varies between 100% and 120% of the width of the wider entry leg. 2 The estimated entry and exit radius are affected by the transition curves of the internal boundaries of entry legs to the circular island.

2.6 Australia

Design Principles

Instructions for the design of roundabouts in Australia and New Zealand have been incorporated into road design manuals issued by Austroads as well as the Queensland State Road Service (Austroads 2009; Department of Main Roads 2006). The general principles governing the design of roundabouts in Australia are:

- The roundabout must be visible and recognizable to drivers prior reaching it; the estimated sight distance depends on the operating speed of the road.
- The number of roundabout legs should not be more than four. However, if all legs have an entry lane, the maximum number of legs could be six.
- Speed reduction is achieved by adjusting the horizontal curvature design of entry legs.
- The width of the circulatory roadway depends on the dimensions of the largest vehicle that uses the roundabout (design vehicle).
- The number of lanes in the entry/exit legs, and the circulatory roadway are designed based on the desired level of service.

The Australian guidelines contain directions for the implementation of roundabouts that depend on the road functional classification as shown in Table 8.

Table 8. Directions for selecting a roundabout in Australia.

Road classification	Interstate – Primary arterial	Interurban road – Secondary arterial	Collector road	Local road
Freeway	D	E	E	E
Interstate – Primary arterial	B	B	C	C
Interurban road – Secondary arterial	n.a	B	B	C
Collector road	n.a	n.a	A	B
Local road	n.a	n.a	n.a	A

A: Suitable selection; B: Possibly suitable selection; C: Not suitable selection; D: Unsuitable selection for the main road, possibly suitable for level junctions on converging legs; E: Unacceptable.

Roundabout Types

The Australian guidelines do not categorize roundabouts; however, different design approach is envisaged depending on the number of lanes for the entry/exit legs and the circulatory roadway. The guidelines provide the possibility to add an exclusive left-turn lane for connecting adjacent legs with high traffic volumes (note: Australians drive on the

left side of the road). These left-turn lanes merge into the exit leg by using an acceleration lane. Additionally:

- The number of entry lanes is estimated based on the estimated level of service. However, if any of the converging roads has two lanes per direction, these will be maintained.
- The number of lanes on the circulatory roadway after each entry, is equal to or higher than the number of lanes of the entry leg; a lane on the circulatory roadway may be dropped after an exit.
- The number of exit lanes must not exceed the number of lanes on the circular roadway.
- The diameter of the central island is determined by the speed limit of converging roads (i.e., the higher speed limit affects the design). It also depends on the largest vehicle to be served (design vehicle). The minimum diameter values for the central island without a mountable part are presented in Table 9.
- The width of the circulatory roadway depends on the diameter of the central island, the number of lanes and the length of the larger vehicle that will use the roundabout. Recommendations for selecting an appropriate width are presented in Table 10.
- The operating speed V85 when entering a roundabout should not exceed 60 km/h. The radius of the successive opposite curves of the entry leg, the circular trajectory, and the exit leg should not exceed 100 m.

Table 9. Recommendations for selecting a diameter value for the central island in Australia.

Entry lane speed [km/h]	Minimum diameter of the central island [m]		Required measures for speed reduction in the entry lane
	Single-lane roundabout	Two-lanes roundabout	
≤40	10–20	16–24	No
50	16–22	16–24	No
60	20–24	28–32	No
70	24–36	36–40	No
80	28–44	40–48	Desired
≥90	28–44	40–48	Mandatory

Table 10. Recommendations for selecting a width for the circulatory roadway in Australia.

Central island diameter [m]	Circulatory roadway [m]	
	Single-lane roundabout	Two-lanes roundabout
10	9.20	n.a
12	8.90–9.90	n.a

(*continued*)

Table 10. (*continued*)

Central island diameter [m]	Circulatory roadway [m]	
	Single-lane roundabout	Two-lanes roundabout
16	6.70–10.90	9.70
20	6.30–12.40	9.30–11.00
24	5.90–11.90	9.00–11.50
28	5.80–11.40	8.80–12.50
32	5.60–10.90	8.60–13.90
36	5.40–10.50	8.40–13.50
40	5.20–10.10	8.20–13.10
46	5.10–9.60	8.10–12.60
52	4.90–9.20	7.90–12.20
60	4.80–8.60	7.70–11.60
70	4.80–8.00	7.60–11.00
80	4.80–7.60	7.50–10.60
90	4.80–7.20	7.40–10.20
100	4.80–6.90	7.30–9.90
120	4.80–6.30	7.20–9.30
140	4.80–6.00	7.10–9.00
160	4.80–5.70	7.0–8.70

3 Comparison Analysis

The analysis of the design guidelines for roundabouts in six countries of different continents has shown that in general the design follows similar fundamental principles, that may be summarized as follows:

- The roundabouts are applied on both urban and interurban roads. In urban areas, the central island is usually surrounded by a mountable strip to facilitate the movement of heavy vehicles. Especially for urban roads, the design of mini roundabouts foresees a completely mountable central island.
- The roundabouts are categorized based on their inscribed circle radius; increasing the radius improves the level of service. The feasibility of applying a roundabout on an intersection depends on the traffic volumes of the converging roads.
- On highways and expressways, the application of roundabouts is prohibited.
- The application of roundabouts is preferred when policy-makers aim to change the drivers' behavior prior reaching an intersection, such as when a road changes from interurban to urban or when the road's cross-section changes.

Roundabouts have become particularly attractive for existing intersections, partially due to their simplicity for providing right-of way to vehicles moving in the roundabout over incoming vehicles. Their application offers advantages over other types of intersections because they are characterized by a high degree of safety and a satisfactory level

of service without using traffic signals. Roundabouts are safer compared to other types of intersections, since they are designed to reduce vehicles' speed and engage a low number of possible collision points. The provided level of service depends on the distribution of the total traffic volumes to respective roundabout legs. The roundabout design aims to combine two principles, which are often in conflict with each other, namely the achievement of a high level of road safety and the ability to provide a satisfactory level of service for high traffic volumes. The differences among the examined national roundabout guidelines mainly concern the way in which these two criteria are approached within the design process. The need to serve high traffic volumes when designing a roundabout, results to increased speeds and the additional lanes that permit the parallel movement of vehicles. More specifically:

- The entry legs are occasionally designed tangentially to the circulatory roadway, in order to increase the entry, circular and exit speed. However, this configuration, deteriorates the level of safety since the vehicle speed increases and the drivers' visibility range decreases.
- The entry/exit legs and the circulatory roadway are widened with more than one traffic lane. However, the vehicles' parallel movement along these segments increases the number of conflict points, which deprives the roundabouts' advantage of having a low number of possible conflict points.

The UK and the Australian roundabout guidelines promote the application of roundabouts by using more than one lane on entry/exit legs and in the circulatory roadway. In contrast, continental European countries emphasize on road safety by limiting the application of roundabouts to non-divided roadways and low road functional classes. For example, in Germany, the technical Directive RAL 2012 recommends the application of roundabouts on single-lane roads that are classified as inter-county roads or lower functional class (Forschungsgesellschaft für Straßen- und Verkehrswesen 2012). In the Netherlands, the technical directive for the design of interurban roads does not consider the application of roundabouts for roads on the principal road network (i.e., classified as national or provincial) (CROW 2013).

4 Conclusions

In the 1950s with the increase of motorized traffic and the widespread use of traffic lights, roundabouts were abandoned. However, in the late 1990s, with the introduction of a simple and uniform rule of priority, according to which, the vehicles entering the junction (i.e., roundabout) must give priority to the vehicles already moving inside the junction, the problem of traffic congestion was radically addressed. As a result, a systematic study for the implementation of roundabouts begun, for providing a sufficient degree of road safety and a satisfactory level of service, without the use of traffic lights. Many countries then proceeded to the formation of technical guidelines for the design, scope, dimensioning and operation of roundabouts. Over time and with the acquisition of experience the technical guidelines evolved significantly. This paper aims to briefly present the guidelines of the most advanced/ experienced countries in roundabout design in order to guide public administrators and engineers that implement relevant studies.

All national technical guidelines are governed by the same basic design principles and determine the traffic volume service possibilities according to the geometric characteristics of the roundabouts. The main differences concern the exact scope and dimensioning of the individual geometric elements, as any attempt to increase the level of service is to the detriment of the degree of road safety provided. Given that in modern times road transport, but also the transport sector, has acquired an international character, it is appropriate, at least at European level, to apply roundabouts at roads of similar functional classification and to design them based on uniform rules.

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