Turbo-roundabout use and design

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The turbo-roundabout concept has recently emerged in the Netherlands as a viable alternative to conventional multiline roundabouts, aiming to solve a set of functional problems related to the weaving maneuvers in the entry and negotiation zones. Although this is a recent concept, the Dutch experience has been showing that it is an extremely efficient solution, mainly in terms of safety. In fact, using physical raised elements in the entrances, ring and exit zones it is possible to define a spiral path which links the entry to the desired exit with a high safety level. These results have justified the concept dissemination to other European countries and the development of some design guidelines.

At the moment, the construction of a turbo-roundabout in Portugal is under study. Therefore, this paper is focused in the turbo-roundabout concept and its general characterization. The different turbo-roundabout layouts are presented as well as their application domain. Based on the Dutch and Slovenian manuals, some general rules and specific geometric design are presented too. The general dimensions for a turbo-roundabout are specified and rules for the quality evaluation of the global solution are explained.

Finally, in order to test the applicability of the concept, the general design guidelines were used in a real case study, converting a double-lane conventional roundabout into a turbo-roundabout. Using some performance indicators, the predictable operating performance of the turbo-roundabout is compared to the initial solution.

Keywords: Turbo-roundabout; geometric design; performance level; safety

1 Introduction

Conventional roundabouts are excellent solutions for traffic regulation, traffic calming, urban regeneration and landscaping. They lead to good traffic conditions and increased safety. This solution has been disseminated all over the world, namely in Portugal since the 1980s. Nowadays they are mostly used on urban ring roads and in suburban areas. To respond to high capacity requirements, the most used solution is the double-lane roundabout.

In spite of the good performance levels, the international experience over the last years has been showing some functional problems in double-lane roundabouts. The most common problems are related to the driver behaviour along the entry, circulatory carriageway, and exit zones of the roundabout. This solution introduces the possibility of lane changing on the roundabout disregarding lane markings, cutting the trajectory curvature and achieving higher speeds. Also the lack of legal framework specifically applicable to roundabouts results in a significant increase on the number of conflict points. These behaviours raise safety problems and risk of accidents, mostly without serious injuries but affecting the normal traffic flow. This risk tends to increase with the increase in the number of lanes, which induces a high level of weaving maneuvers.

The turbo-roundabout concept emerged in the Netherlands in the late 1990s in order to solve problems related with the weaving maneuvers in the multiple lane roundabout circulatory carriageways at the entry and exit zones. This concept is recent and the scientific studies related to
it are still very scarce. This new solution has the following presuppositions: (i) no lane changing on the roundabout and near the entry and exit and; (ii) low driving speed near and through the roundabout because of the raised lane dividers.

This behaviour control is a consequence of the physical elements that separate the circulation lanes near the entries, circulatory path and exit zones which define spiral and continuous paths between the entry and the desired exit. By eliminating the usual crossovers of the conventional roundabouts, the safety level increases significantly.

During the last decade several turbo-roundabouts have been constructed with good results, mostly in countries from northern Europe. Different layouts were developed and implemented according to the local specifications and requirements. Compared to the traditional double-lane roundabout, the international literature refers three important advantages for turbo-roundabouts: (i) lower number of potential conflict points during the roundabout crossing path; (ii) slower speed before, along and after the turbo-roundabout crossing; (iii) and low risk of side-by-side accidents. However, the research works point some possible disadvantages to this new solution, mostly related to the left-turn maneuvers and to the general decrease of capacity levels. Some authors state that only in very specific and rare circumstances of traffic distribution, the turbo-roundabout can offer more capacity than a two-lane conventional roundabout of similar size.

In this context, this work introduces the turbo-roundabout concept and provides some general guidelines regarding its geometric design based on the Dutch and Slovenian manuals and practical experience. Additionally, the turbo-roundabout performance is compared with conventional roundabouts taking into account safety and capacity performance indicators. This comparison is based on a real case study using a normal double-lane roundabout, located in the city of Lisbon, and evaluating its real capacity levels.

It was concluded that the turbo-roundabout offers higher levels of safety by improving deflection and reducing the number of conflicts. The capacity levels of the original roundabout were compared to the expected capacity levels for a developed turbo-roundabout solution and the general capacity decreased about 3%. This decrease is not substantial particularly when compared with the expected safety increase achieved. Additionally, this new layout led to a substantial reduction of the occupancy space, which enhances the reallocation of the remaining space for other urban activities or other users including pedestrians or cyclists.

2 The Turbo-roundabout Concept and Characterization

2.1 The concept
The turbo-roundabout concept emerged in 1996 in the Netherlands by Lambertus Fortuijn, a researcher from the University of Delft, in order to solve existing problems in the multilane conventional roundabouts. The most common problems in the conventional multilane roundabouts are related with the driver behaviour along the entry, circulatory carriageway, and exit zones of the roundabout where it is possible to observe the lane changing into the roundabout disregarding lane markings, cutting the trajectory’s curvature and achieving higher speeds. This new solution has the following presuppositions: (i) no lane changing on the roundabout and near the entry and exit and; (ii) low driving speed near and through the roundabout because of the raised lane dividers.
In the turbo-roundabout the drivers are forced to follow a specific path according to their intended destination (see Figure 1). The carriageway consists of continuous spiral paths, using curbs to separate lanes in the entry, circulatory and exit zones (Mauro and Branco, 2010) – see Figure 2. The installation of curb dividers has two major implications: elimination of conflict points caused by weaving maneuvers, and speed reduction due to increased deflection (Fortuijn, 2007).

The first turbo-roundabouts were installed in 2000, also in the Netherlands. After that, countries as Poland, Germany (Brilon, 2005), Finland, Norway and Slovenia adopted this new solution too. Nowadays, more than 190 turbo-roundabouts are implemented in the Netherlands and some design guidelines have been published (April, 2008_CROW, 2008). The Dutch government no longer constructs multi-lane conventional roundabouts, adopting turbo-roundabout as current practice (Fortuijn, 2009).

![Figure 1. Turbo-roundabout](image1)

![Figure 2. Curbs at the exit of the turbo-roundabout](image2)

2.1 Layouts and scope

Depending on the traffic demand distribution, a turbo-roundabout can have different layouts (CROW, 2008) and the central island is frequently no circular. The dominant flow is the most important factor when choosing the appropriate layout. Figure 3 presents the most common layouts based on dominant flows, which cover a wide range of traffic situations.

![Figure 3. Turbo-roundabout layouts: (a) Oval; (b) Knee; (c) Spiral; (d) Rotor](image3)
The layout (a) is the most appropriate when traffic demand in the secondary lane is low. In this case, the secondary entry can have one (Oval) or two lanes (Standard). When right turns are high, the solution can have a bypass (Knee), as shown in layout (b). The layout (c) (Spiral) is particularly useful when the through traffic flow is dominant but both the right and left turns are also significant. Finally, layout (d) is suitable when the traffic demand is evenly spread between the four arms.

2.3 Turbo-roundabout's performance

Compared to the traditional double-lane roundabout, the international literature refers three important advantages for turbo-roundabouts: (i) reduction in the number of conflicts; (ii) speed reduction along the entry, circulatory and exit zones; (iii) and low risk of side-by-side accidents (Corriere and Guerrieri, 2012; Fortuin, 2009; Giuffrè et al., 2010; Guerrieri et al., 2012).

The literature is in agreement about the safety increases, however this consensus isn't valid for the capacity results. In fact, the main disadvantages pointed by the literature for this new solution, are related to the left-turn maneuvers and to the general decrease of capacity levels.

2.2.1 Safety Level

Raised dividers on turbo-roundabouts force drivers to stay on the correct lane and, consequently, to follow paths with smaller radius at reduced speeds. While on a two-lane roundabout a driver can ignore lane markings, choose an almost direct path and maintain its approach speed, on a turbo-roundabout all drivers must follow similar paths, resulting on homogenous low speed profiles. The comparison of the number of conflict points also suggests safety improvements (see Figure 4).

![Figure 4. Conflict points in a conventional double-lane roundabout and in a turbo-roundabout](image)

It is visible a reduction from 24 conflict points in the double-lane roundabout to 14 points in the turbo-roundabout, indicating a global reduction in the crash probabilities. One should note, however, that some of these conflicts have a higher severity, not only because of the increased impact angle, but also because circulating traffic is concentrated on the outer lane. In the absence of historic crash data, this research field justifies a more in depth analysis, namely using microsimulation techniques.
Several studies suggest a 70% lower crash risk when a double-lane roundabout is converted into a turbo-roundabout (Fortuijn, 2009). Other studies, based on conflict analysis techniques applied to 9 layouts with different demand scenarios, show a 40-50% reduction in the accident rate (Mauro and Cattani, 2010). In a study based on microsimulation applications, Fortuijn (2007) concluded that drivers using the outer lane of a turbo-roundabout drive slower than in the double-lane roundabout, with reductions from 48 to 38 km/h. One factor responsible for the speed profile of a driver through movement is the path curvature (inverse of radius). This is because driving inconvenience increases with the centripetal acceleration (AASHTO, 2011), which varies directly with curvature.

2.2.2 Capacity
Although the safety benefits are widely recognized, there are still doubts about improved capacity. Some authors, using simplified approaches, concluded that turbo-roundabouts offer better capacity than conventional roundabouts of similar size (Corriere and Guerrieri, 2012; Fortuijn, 2007). However, these conclusions are not consensual in the scientific community (Bastos Silva et al., 2011; Mauro and Branco, 2010).

Recent Portuguese research disregards these conclusions (Bastos Silva et al., 2011; Vasconcelos et al., 2012). It seems necessary a new approach and calculation methodology to measure the real capacity levels on turbo-roundabouts (Vasconcelos et al., 2012). These new studies have concluded that the capacity in a turbo-roundabout tends to be slightly below the capacity in a conventional double-lane roundabout with equivalent dimensions and with similar traffic demand conditions. These results were expected because the turbo-roundabout is a more inflexible solution than the normal roundabout.

However, for the standard layout, some traffic demand conditions were identified where the capacity in the turbo-roundabout can be slightly above the capacity in the normal double-lane roundabout. It can happen when: (i) increases the number of right turns on the secondary lane; (ii) increases the go-ahead movement in the dominant flow; (iii) there is an equilibrated traffic distribution in all arms and directions of the turbo-roundabout.

2.3 Final considerations
The turbo-roundabout solution, with its different layouts, is a way to solve the safety problems of multi-lane roundabouts.

The reduction of the number of conflict points and the increase of deflexions levels reducing the speed result in a significant increase of safety in the turbo-roundabout when compared to the conventional double-lane roundabout.

In terms of capacity, the results are not consensual. Some authors, following simplified methodologies, concluded that turbo-roundabouts lead to an increased capacity when compared to conventional roundabouts of similar size. However, other authors reveal that only in very specific and uncommon scenarios in real-world networks can a standard turbo-roundabout be expected to provide more capacity than the equivalent double-lane roundabout.
3 General design guidelines

3.1 Geometric design

The geometrical shape of the spiral course present in the circulatory roadway is given by the simultaneous development of two nested spirals, each with three segments of circular arcs with consecutive larger radii, and the centre points respectively to the left and right side of the geometric centre. Each change within the radius must be matched by a shift of its centre over a line called the translation axis, in such a distance which ensures that the spiral remains continuous. The diagram that gathers those spirals over the translation axis segment is called a "turbo-block", a key tool in the design of a turbo-roundabout, as it represents the boundaries of the traffic lanes.

The dimensions of this turbo-block must always ensure that the drive through speed does not exceed 40 km/h, and at the same time accommodate the swept path of the design vehicle, which requires a suitable selection of the lanes radii and width. Due to the fact that all the swept paths are wider, when the radius is tighter, there is a need to introduce an extra width to the inner lane that will decrease throughout the development of the spiral. This calculation is obtained by computer tools that draw the swept path of the design vehicle through the circulatory carriageway, without crossing neither the traversable part of the central island, or the physical lane divider. To obtain this extra width, instead of having two centre points, one must have four central points: two right-side points and two left-side points. The distance between the outer points is referred to as Δv, and between the inner points as Δu. The outer points are used for the innermost circular arcs (R₁), representing the outer boundary of the central Island (thereby the inner boundary of the inside lane). The remaining circular arcs (R₂, R₃ and R₄) are achieved through the inner points. Figure 5 shows a turbo-block detail suitable for a Standard or Egg-Shaped layout.

![Turbo-block detail](image)

**Figure 5.** Turbo-block detail

The geometric design process begins with the definition of the basic dimensions, such as the inner radius of the inside lane (R₁), the width of the traffic lanes (Lᵢ and Lₑ), and the width of the lane divider (Lₛ) – see Figure 6.
For the previous example, Table 1 shows the mathematical process required to obtain the remaining dimensions, in the most common layouts.

<table>
<thead>
<tr>
<th>Element</th>
<th>Width (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R_1$</td>
<td>12.00</td>
</tr>
<tr>
<td>$R_2$</td>
<td>12.00+5.15=17.15 $R_3$= $R_1$+L (average)</td>
</tr>
<tr>
<td>$R_3$</td>
<td>17.15+0.30=17.45 $R_4$= $R_2$+Ls</td>
</tr>
<tr>
<td>$R_4$</td>
<td>17.45+5.00=22.45 $R_5$= $R_3$+Le</td>
</tr>
</tbody>
</table>

The shifts of the centre points ($\Delta v$ and $\Delta u$) can be determined by observing the geometrical behaviour of the inner lane lines in a cross-section as shown in Figure 7. In this example the inner line shifts 5.35 meters ($\Delta v$) in the transition between the inner lane and the outer lane, while the outer line only shifts 5.05 meters ($\Delta u$).

In the geometrical design of turbo-roundabouts, it’s a standard procedure to adopt some dimensional classes each one with pre-defined dimensions. Thus, for each of the basic type layouts, four standard solutions are established, referenced by the value of the radius in the inner verge of the carriageway ($R_1$), and by the remaining geometric parameters which are based upon this dimension. The dimensional classes are:

- $R_1$ = 10.50 meters;
- $R_1$ = 12.00 meters;
- $R_1$ = 15.00 meters;
- $R_1$ = 20.00 meters.

According to (CROW, 2008) any design should begin by the class that minimizes drive through speed ($R_1$=12.00 meters), only using the upper classes if the traffic characteristics require it. The class $R_1$=10.50 meters should only be used exceptionally in locations where space constraints do not allow the establishment of other solutions. The geometric design process
Table 2. Main dimensions on a standard turbo-roundabout

<table>
<thead>
<tr>
<th>Element</th>
<th>Dimension (m)</th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>R₁</td>
<td>R₂</td>
<td>R₃</td>
<td>R₄</td>
</tr>
<tr>
<td>Inner Lane</td>
<td></td>
<td>10.50</td>
<td>12.00</td>
<td>15.00</td>
<td>20.00</td>
</tr>
<tr>
<td>Outer Lane</td>
<td></td>
<td>15.85</td>
<td>17.15</td>
<td>20.00</td>
<td>24.90</td>
</tr>
<tr>
<td>Inner radius</td>
<td></td>
<td>16.15</td>
<td>17.45</td>
<td>20.30</td>
<td>25.20</td>
</tr>
<tr>
<td>Outer radius</td>
<td></td>
<td>21.15</td>
<td>22.45</td>
<td>25.20</td>
<td>29.90</td>
</tr>
<tr>
<td>Inner Lane</td>
<td></td>
<td>5.70</td>
<td>5.30</td>
<td>5.10</td>
<td>5.10</td>
</tr>
<tr>
<td>Start width</td>
<td></td>
<td>5.00</td>
<td>5.00</td>
<td>4.90</td>
<td>4.70</td>
</tr>
<tr>
<td>End width</td>
<td></td>
<td>5.35</td>
<td>5.15</td>
<td>5.00</td>
<td>4.90</td>
</tr>
<tr>
<td>Average width</td>
<td></td>
<td>5.00</td>
<td>5.00</td>
<td>4.90</td>
<td>4.70</td>
</tr>
<tr>
<td>Outer lane width</td>
<td></td>
<td>0.30</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane divider width</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Distances between outer centre points</td>
<td>Δv</td>
<td>5.75</td>
<td>5.35</td>
<td>5.15</td>
<td>5.15</td>
</tr>
<tr>
<td>Distance between inner centre points</td>
<td>Δu</td>
<td>5.05</td>
<td>5.05</td>
<td>4.95</td>
<td>4.75</td>
</tr>
</tbody>
</table>

3.2 Signing
The effective use of a turbo-roundabout requires that any decision about the intended destination has to be made before reaching the circulatory roadway. From that perspective, the use of an effective traffic signalling has great relevance, in order to provide clear and timely information about the multiple paths, and how to deal with the multi-lane approach to the roundabout. Therefore, the selection and assignment of correct pathways in the entry lanes is extremely important, since the design characteristics of the spiral course do not allow the driver to change traffic lanes inside the circulatory carriageway, making it difficult to drive the full circle to rectify a potentially wrong decision.

In the scope of signposting on double-lane approaches are worth mentioning the pre-intersection boards. This type of signs, controlling the lane use, adopts a graphical diagram with specific characteristics, which translates the geometric layout of the geometric solution and contains the destinations for each of the directions, as well as the identification of roads associated with them. This roundabout signs should be placed either above or preferably in the verge of each approach. In the later, the information is commonly presented in a single panel placed on the right side of the approach, or divided into two individual panels using the splitter island to place the information regarding the left lane of the approach. Figure 8 shows a real example of different signposting mounting on the approach of turbo-roundabouts near the city of Delft (the Netherlands).
The same way as the signposting, the pavement marking is a crucial aspect in order to ensure the correct understanding of the available paths. In this context (Fortuijn, 2011) considers essential, alongside with the pre-intersection boards, the use of arrow-shape legends that mimic the information carried on those. These arrows, also known as “fish-hook”, should be placed within each of the entry lanes, and must have compatible dimensions with a driving speed of 50 km/h, and should be arranged in groups of at least four consecutive units (CROW, 2005). Figure 9 shows some of the graphical configurations designed for this purpose.

The use of this kind of markings inside the circulatory roadway is regarded as redundant when inserted into physically delimited spiral circuits, and therefore not recommended.

![Figure 9. Arrows used on entry lanes](image_url)

### 4 Case Study

#### 4.1 Scope and overview

The object of this case study is the Baden-Powell Square, in Lisbon, which features a double-lane conventional roundabout with geometric and traffic demand characteristics compatible with its transformation into a turbo-roundabout (Gaspar, 2013). This roundabout built in the early 60’s, is mainly characterized by the heterogeneity of its various geometric elements, including the four legs and the circulatory roadway with geometric characteristics quite distinct from each other. This is mainly due to the fact that it was built following the traditional concept of large circular plazas, not complying with any regulations in fact non-existent in Portugal at the time of its construction.

It was found that the overall size of the roundabout is higher than the reference values for such infrastructures (ICD ≈ 66 meters) without any proof of significant benefits in terms of performance. Additionally, it is possible to notice in Figure 10_a, the oversized double-lane circulatory carriageway, with a cross-section of approximately 12 meters wide, which promotes the overtaking within the circulatory lanes and also higher speeds due to the lower amount of deflection imposed to the vehicle’s path.

The characterization of the existing traffic demand was based on peak hour volume counts conducted in January of 2012, using video footage and subsequent treatment of the collected data. That information was then converted into passenger car equivalents per hour (pce/h), using the converting factors given in the (FHWA, 2000). The traffic distribution diagram is shown in Figure 10_b.
In order to evaluate the current levels of capacity, it was decided to apply to the existing traffic demand a probabilistic-based model developed by (Brilon, 2005), whose basic formulation, by removing the variables related to geometric characteristics, allows its use both in conventional roundabouts and in turbo-roundabouts:

\[
Q_e = 3600 \times \left(1 - \frac{t_{\text{min}} \times Q_c}{n_k \times 3600}\right) \times \frac{n_z}{t_f} \times e^{-\frac{Q_c}{3600} \left(\frac{t_{\text{c}}}{2} - t_{\text{min}}\right)}
\]

where,
- \(Q_e\) – Basic capacity of one entry (pce/h);
- \(Q_c\) – Traffic volume on the circle (pce/h);
- \(n_k\) – Number of circulating lanes
- \(n_z\) – Number of entry lanes
- \(t_c\) – Critical gap (s);
- \(t_f\) – Fallow–up time (s);
- \(t_{\text{min}}\) – Minimum gap between succeeding vehicles on the circle (s).

According to the results of the probabilistic-base model described above, Figure 11_a shows that the existing roundabout has a general capacity of about 6222 pce/h. Similarly, it is possible to analyse the degree of saturation, meaning the ratio of the demand at the roundabout entry to the capacity of the entry (see Figure 11_b). The result shows that all the entries are far below the reference value of 85% of its capacity, allowing a potential increase in traffic demand.

Figure 10. a) Survey Plan; b) Traffic distribution diagram

Figure 11. Turbo-roundabout: a) Existing entry capacity; b) Existing degree of saturation
4.2 Proposed solution
The geometric solution, taken into account the traffic counts carried out, was to focus primarily on choosing the correct geometric layout, consistent with the traffic distribution and the existing road network. Thus, it was shown that the existing roundabout fulfils one of the requirements associated with privileged terms of use of a turbo-roundabout, namely being a competitive alternative to an existing intersection with a main flow, with high debit value (in this case North-South direction), and a side flow with relatively minor importance. These features are suitable for the use of a turbo-roundabout with a standard geometric layout.

The proposed solution was developed through the design process described before, with $R_1=12$ meters, being the configuration that ensures the most suitable drive through speed (37-39 km/h) according to (CROW, 2008). The geometrical parameters adopted for this solution are summarized in Table 3.

<table>
<thead>
<tr>
<th>Element</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Entry radius ($R_e$)</td>
<td>12.00 (m)</td>
</tr>
<tr>
<td>Exit radius ($R_x$)</td>
<td>15.00 (m)</td>
</tr>
<tr>
<td>Turbo-block rotation</td>
<td>61° (CW)</td>
</tr>
<tr>
<td>Entry/Exit lanes width</td>
<td>3.50 m</td>
</tr>
</tbody>
</table>

Figure 12 shows a general layout with the proposed standard turbo-roundabout on the existing road network. In this figure it is possible to see the process of matching the cross-sections of the roundabout legs with the existing ones. Generally, the turbo-roundabout ensures more compact solutions than their conventional counterparts, particularly in this case where the original roundabout was oversized, an important aspect that stands out is a substantially reduction in land use of approximately 2500 m².
4.3 Performance evaluation of the solution

In order to quantify the level of service of the proposed geometric layout, the previously described probabilistic-base model was applied. Figure 13.a shows a comparison between entry capacity in the existing and proposed solution and Figure 13.b shows the degree of saturation in the entries of the turbo-roundabout.

![Graphs showing performance evaluation](image)

Figure 13. a) Turbo-roundabout entry capacity compared to the existent roundabout; b) Turbo-roundabout degree of saturation compared to the existent roundabout

The results show that, in general, the level of service ensured by the turbo-roundabout is proportional to the current capacity levels, just slightly lower. This decrease is justified by the existence of a single-lane circulatory roadway, which concentrates the circulating flow at the confluence of the main flow entries (North and South), reducing the critical gap. On the other hand, the side flow entries (East and West) concentrate in the left lane the through and left turn movements, blocking the flow balance effect typical of conventional roundabouts where the driver who wants to move forward tends to choose the lane with the shorter queue. Thus, the capacity of side flow entries depends strongly on the scale of the left turn movements. These results are in line with the ones recently published by authors that evaluated the performance of turbo-roundabouts by the use of conventional models (Mauro and Branco, 2010) or by applying microsimulation techniques (Bastos Silva et al., 2011). The one exception occurs in the East entry, where the estimated capacity nearly doubled the original, as a result of the new double-lane approach.

Overall, the level of service is similar. The estimated general capacity of the intersection went from 6222 pce/h from the existing conventional roundabout to 6050 pce/h in the turbo-roundabout proposal, which represents a decrease of approximately 3%.

The results support the conclusion that in the North entry, despite the increase of 11%, the degree of saturation remained below the reference value. Similarly, in the South entry, despite the increase of 12%, the degree of saturation remained in about half the amount of the reference value, allowing a potential traffic growth. The East entry has a lower degree of saturation, due to lane duplication, thereby increasing its capacity. Finally, in the West entry, despite the increase of 3%, the degree of saturation remained also below the reference value.

In conclusion, this case study proved that the transformation of the existing roundabout into a standard turbo-roundabout, resulting in a small decrease of 3% in the overall capacity of the intersection, was not substantial, especially when compared with the expected safety increase
achieved, and potential reallocation of the remaining space for other urban activities or other users such as pedestrians and cyclists.

5 Conclusions
The turbo-roundabout is a recent concept which emerged in the Netherlands as an alternative to the conventional multi-lane roundabouts. The Dutch experience has been confirming the expected results, mostly in terms of safety. The reduction of the number of conflict points and the deflexion level control justify the reduction of accidents in 80% as some literature shows. It was concluded that the performance in terms of capacity is not consensual. However, in some specific conditions the turbo-roundabout solution can be extremely useful, putting together safety and capacity benefits.

At the moment, the construction of a turbo-roundabout in Portugal is being considered and a more extensive study is necessary in order to improve the geometric construction knowledge. In this line of work, this paper aimed to present the turbo-roundabout's benefits and give a contribution to define some design guidelines to help its geometric conception. The turbo-roundabout has more rigorous guidelines than conventional roundabout but with an easy application. In opposite to the conventional roundabout, which has a unique centre, the turbo-roundabout conception is based on two centres separated with an equal distance of the lanes width in the ring. These two centres support the turbo-block construction allowing the definition of spiral paths. Also, it was concluded that with the exception of the turbo-block construction, all the other geometric guidelines and quality validation rules are applicable to both conventional roundabouts and turbo-roundabouts.

The applicability of the concept was tested by turning a real roundabout into a turbo-roundabout. This operation included a diagnostic analysis to evaluate some predictable effects directly related to the new solution.

It was concluded that there were evident benefits in terms of safety, however the capacity levels in two entries had a slightly decrease without achieving their limit. In general, the intervention tends to be a positive change resulting in speed reductions and in additional free space which can be used to improve the circulation of other transport modes (walking or cycling, for instance) or for landscaping requalification.

References

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