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Eight Traffic Calming "Easy Pieces" to Shape the Everyday Pedestrian Realm

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Abstract: The need for safe pedestrian movement implies subtracting and modifying space dedicated to vehicles, especially in urban areas. Traffic control measures aim to reduce or modify the width of the carriageway and force the correct use of the space by pedestrians through two approaches: the former is hard and includes physical barriers and the latter is soft and induces psychological fashion effects on the drivers. This paper presents vertical and horizontal devices integrated by landscaping, planting, or other similar works to slow motor vehicle speed, narrow traffic lanes, and/or create smaller distances for pedestrian crossings. Mobility and boundary issues are considered to discuss their warrants and potential impacts. Indeed, the effects of speed or volume treatments should be investigated through a comprehensive multicriteria analysis without overlooking pedestrian level of service, access and connectivity to residents and emergency vehicles, drainage and snow issues, loss of on-street parking lots, and environmental goals in terms of noise and emissions to air reduction.

Keywords: traffic calming; horizontal devices; vertical devices; pedestrian mobility; walkability

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1. Introduction

Road safety is a major health burden at the international level because it causes 1.35 million deaths [1] and more than 50 million physical injuries and disabilities [2] every year. Road accidents pose a serious issue, especially in urban areas where urbanisation and mobility demand have grown and still heighten the interaction between traffic and the surrounding environment [3]. It implies increasing health costs due to crashes whose risk for road users is higher than citizens' exposure to natural or anthropogenic events [4], even at the district scale [5]. On the other hand, social consequences in terms of the liveability of urban spaces [6], noise [7,8], air pollution [9,10], urban heat island [11], soil contamination and imperviousness [12,13], congestion [14,15], and neighbourhood unsatisfaction [16] cannot be overlooked. Due to increasing environmental attention, a new consciousness is changing how citizens move across the city [17], and slow and light mobility plays a pivotal role in this cultural change promoted after the COVID-19 outbreak [18]. The increasing demand for alternative transportation modes forces radical changes in urban layout [19] from car-centred to proximity-based cities [20]. Proximity among city areas, especially to green spaces and services, shortens spaces and time, and favours the neighbourhood relationship [21]. The transport demand modification impacts urban dynamics and requires transport infrastructures' appropriate layout to ensure comfortable and safe movements for new road users [22]. More specifically, pedestrians and bicycles need proper infrastructures designed for everyday activities in car-centred cities [23,24], with full requirement-meeting when it comes not only to safety, but also comfort, security, and attractiveness, which calls for specific surveys starting from the users' perception of the urban environment they move within [25]. On the road, vulnerable users (i.e., pedestrians, bicyclists, and two-wheeler riders) conflict with vehicles with larger dimensions and masses. Therefore, they are the "fragile" component in the event of a crash [26], although social costs are often underestimated [27]. Mobility of "vulnerable users" needs design criteria that safely places motorised and non-motorised flows (either by physically separating them or having them sharing the same space) [28] and manages conflict points thanks to vehicular speed reduction because the faster the speed of cars, the higher crash risk and severity in crashes. In particular, the difference in mass between pedestrians and motor vehicles causes the former the most severe injury. Indeed, fatality incidence rises from 5% at 20 mph (32 km/h) to 45% at 30 mph (48 km/h), and 85% at 40 mph (64 km/h) [29]. Geometry and kinematics of traffic movements significantly impact the risk management of urban intersections when vulnerable users or light vehicles interact with heavy vehicles [30,31]. Likewise, it is important to associate the geometry of roads with the appropriate vehicular flows. The concept of traffic calming moves from the above and summarises different technical solutions to slow motor vehicles through commercial and residential areas and increase safety for vulnerable users [32]. Traffic is not eliminated but is regulated to reach just origins or destinations and avoid through-traffic (especially due to cruising for parking). The speed drops to less than 30 km/h and reduces the negative impacts of cars on the urban environment [33] and vulnerable users, such as students and elderly people [25]; the ultimate goal is to create pedestrian realms by designing a continuous network of pedestrian paths, with reduced conflict points, made safer by giving priority to non-motorised modes. All of the above is conducive to great benefits, especially from a sustainability point of view since traffic calming not only meets vulnerable users' safety requirements but also: (i) contributes to mitigate noise and air pollution levels (mainly achieved through low-speed levels and slowing down traffic flows which prevent queues, sudden gear changes, accelerations, and decelerations, which cause the emission of harmful exhaust gases and noise); (ii) saves energy (by optimising transport resources and prioritising walking); and (iii) reduces surface consumption by increasing the space for pedestrians at the expenses of that occupied by cars.

Traffic calming is achieved through changes in road design, which involve many different geometrical and functional transformations [34]. In particular, the most common measures include vertical or horizontal deflections to maintain slow motor vehicle speed [35,36], narrowed traffic lanes to create smaller distances for pedestrian crossings [37], blocked or restricted access to avoid conflict points or signals to control the traffic flow [38]. Therefore, they include chicanes, mid-block neck-downs, altered horizontal and vertical street geometry, 45-degree or 90-degree angle parking, widened footpaths, provision of cycle lanes, and lane narrowing.

Pioneered by the *woonerven*, current residential areas with low-vehicular flows (less than 50 vehicles per hour) are virtually all eligible to become such pedestrian realms, provided to be regulated as Zone 30s or similar, depending on the local highway code standards to enforce traffic calming and reduced speed limits.

This study investigates eight traffic calming scenarios to demonstrate the flexibility of typical urban environments where traffic calming measures can reshape four- and three-arm intersections and mid-block links. Each layout is a possible solution for safety problems that solves punctual conflict points (CP), typical crossing areas, and belongs to the urban system in different locations [39]. For each scenario, both technical and functional issues are considered. Different pavement materials have been proposed to differentiate and highlight conflict points for pedestrians and motorised vehicles. The road pavement scenarios assume existing asphalt surfaces, like most Italian roads. Moreover, the analyses focus on the needs of pedestrians, the problems of rainwater disposal, and the infrastructure capacity according to Grava [40]. Each scenario is conceived to be easily replicable at CPs or mid-blocks at the district level and is specifically designed to reduce vehicular speed and ensure smooth driving style, thus reducing air and noise pollution, saving energy, and reshaping the streetscape to increase surface availability for pedestrians.

1.1. Building the Knowledge

Traffic calming initially consolidated in northern Europe and America and soon propagated elsewhere, with several case studies available in the grey and scientific literature; most notably, a series of handbooks and manuals in the 1990s guided how to design and implement traffic calming schemes. Many of these were issued by governmental bodies to provide directions and examples to replicate at the national level, as in the case of France [41], Denmark [42], Spain [43], or in some other cases, were aimed at introducing the novelty of traffic calming by transferring the best practice from abroad [44].

This dissemination process went hand in hand with more study fields, from the development of technical criteria to design traffic calming [45], to the attempt to frame it within a general redesign of the urban built environment [46], or to use traffic calming as one of the tools to improve walkability [47] and foster the sentiment of belonging among communities [48,49]. However, some prior seminal studies on the role of the urban environment in creating liveability by enhancing walking developed within urban planning theories [50–53] affected a large part of the 1990s literature on traffic calming, thus giving rise to more studies focused on pedestrians as main characters in the streetscape and as a modal priority in everyday mobility behaviours [54,55]. Concurrently, the (at that time) rising environmental concerns generated more studies on the problems associated with vehicular traffic (i.e., noise and air pollution and surface consumption) to which traffic calming and non-motorised modes could provide solutions, starting from empirical evidence [45,56,57].

These pioneering studies from the 2000s generated more case studies and theories, also thanks to the consolidation of several regulatory tools (Zone 30s, environmental islands, green zones, etc.) enforcing traffic calming schemes in cities. Moving from the implementation of speed devices [58,59] as an effective control to increase pedestrians' safety and as a prerequisite to increase liveability, traffic calming has evolved into more design concepts like "road diet" (reducing lanes' number or width to accommodate bike lanes or larger sidewalks) [60], "complete streets" (converting mono-modal roads into the multimodal and multipurpose environment) [61], and "superblocks" (redirecting traffic away from intersections to convert these into civic spaces, as in Barcelona, Spain, also with the help of nature-based solutions) [62]. These concepts' common trait lies in the awareness that traffic calming, when associated with design for all, nature-based solutions, place-making theories, and practice, can be not only a solution to safeguard non-motorised modes but an actual catalyst for urban repurposing. Examples abound worldwide, with Europe initially leading [63], and evidence that traffic calming is no longer just a road safety technique but a major requirement in urban design.

At the same time, studies demonstrating benefits in terms of improved air quality and reduced noise are still thriving, based on several case studies [64,65], as well as those stressing improved liveability [66,67], with great potential in the quality of life of the most vulnerable users [66,68].

2. Methods

The eight traffic calming scenarios, which are further elaborated, are built considering the lessons from the literature reported above and can be considered "easy pieces" to be easily adaptable to and designed for vehicular low-flow areas, mostly residential or with moderate mixed land use, typical of many European consolidated urban areas. All of them can be combined, complementing each other, and creating a continuous pedestrian path, enhancing all the benefits of walking and the environmental potential in generating a pedestrian realm. More specifically, the traffic calming "easy pieces" described next are:

- Four-arm intersection with build-outs.
- Road closure with cul-de-sac and mini roundabout.
- Road closure with narrow U-turn cul-de-sac.
- Three-arm intersection with raised crossing.
- Median opening to create a pedestrian refuge.

- Chicane.
- Crossing area with speed humps.
- Four-arm intersection with diverter.

2.1. Four-Arm Intersection with Build-Outs

A four-arm intersection with build-outs is specifically designed to reduce conflict areas and improve safety by creating sidewalk protrusions or "build-outs", thus enabling pedestrians "to see and be seen" when crossing (Figure 1). Build-outs are designed to allow turning manoeuvres according to cars' travel directions. Figure 1 describes the most common symmetric layout with the following design criteria.

A Limit of the existing sidewalk the protrusion is built upon (Figure 2 as an example).
B Curb extension (build-out) with bollards to facilitate turning manoeuvres.
C 3.50 m-wide one-way carriageway with protrusions shaped to create a parking lane.
D Bollards to direct pedestrians toward the safest point for crossing and to avoid jaywalking.
E Curb reshaped to avoid illegal turning, equipped with low vegetation (h < 50 cm), as in Figure 3; low vegetation can be used, as in B or D and substitute bollards.
F The crossing area is designed to meet universal design requirements and standards. Sidewalks protrude and restrict the carriageway area so that two drivers have difficulty passing through simultaneously. The ramp slope is designed to enable wheelchair users to cross; likewise, the sidewalk grade is maintained for visually challenged and blind users to avoid walking on ramps. The grade and the zebras are equipped with detectable warning surfaces (tactile tiles and metallic plates or "bubbles" on the zebra flat). Low lamps (pencil-like) complete the public lighting system (cut-off lamps to enable pedestrians to see and be seen).

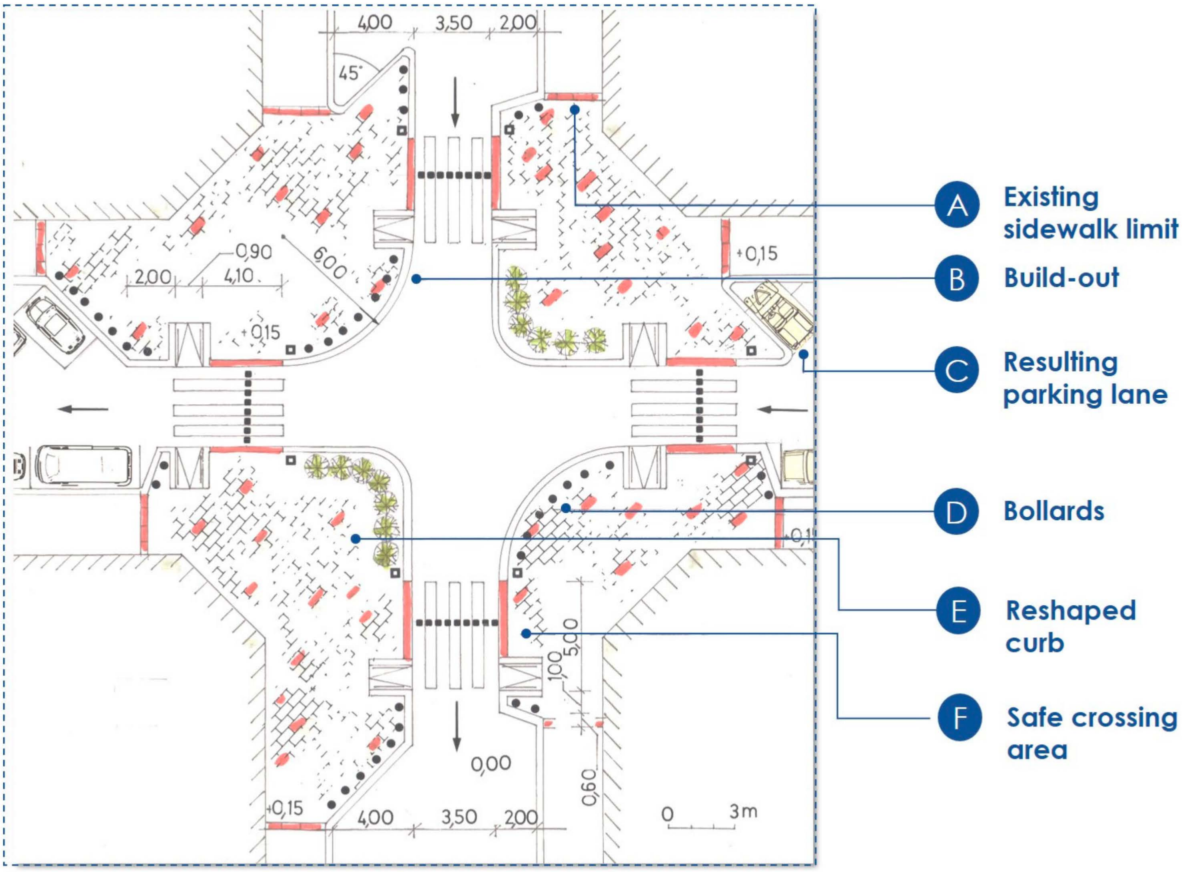

Figure 1. Four-arm intersection with sidewalk advancement (units in m).

(**a**) (**b**)

Figure 2. Protrusion from existing sidewalks (**a**) with different surface textures and colours, San Antonio, TX, USA; (**b**) under construction, Montreal, Canada.

Figure 3. Low vegetation to shape the edge of the sidewalk, Madrid, Spain.

2.2. Road Closure with Cul-de-sac and Mini Roundabout

The closure of a multi-lane road creates a safe environment for pedestrians, connects two opposite sidewalks via a raised crossing, and compels passenger cars to turn around, thus mitigating through-traffic at the district-level (Figure 4).

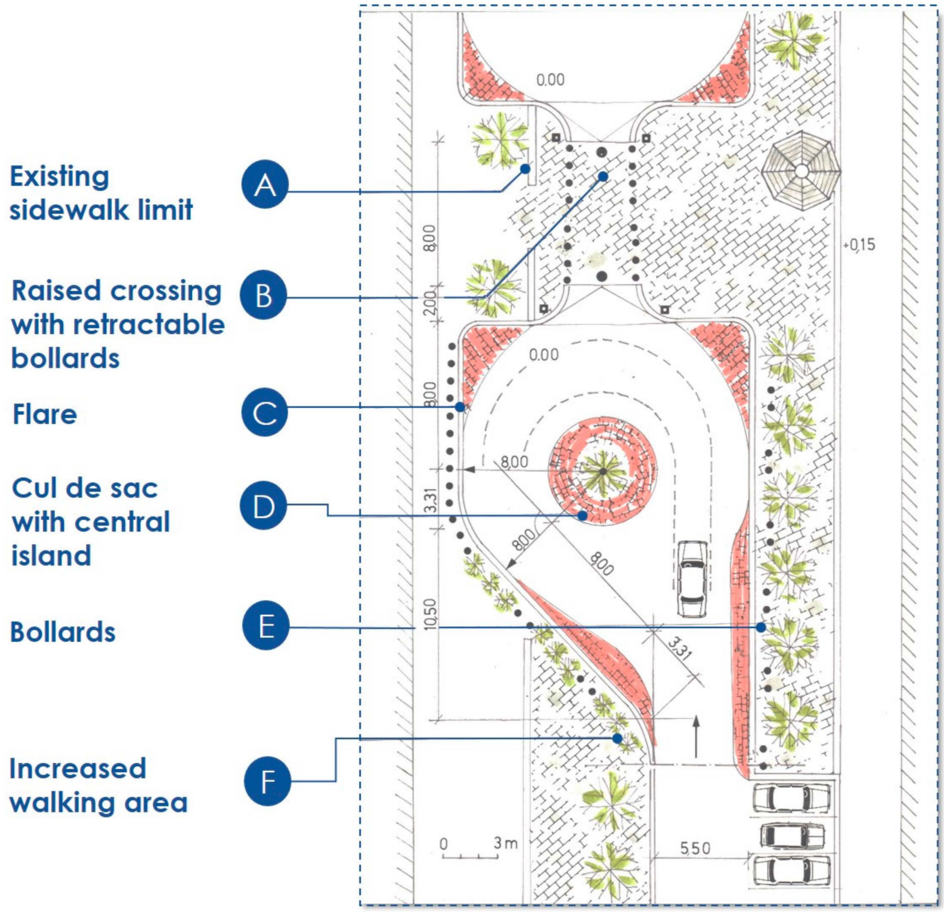

Figure 4. Road closure with cul-de-sac and mini roundabout (units in m).

This layout includes the following:

A Curb of the existing sidewalk.

B This raised crossing environment is designed by creating a single raised area (+0.15 m above the carriageway) connecting the two sidewalks [69]. A retractable bollard restricts vehicular access (Figure 5) except for emergency and utility vehicles, which approach the area via a 7%-slope ramp. Emergency vehicles should be considered when vertical devices are used to avoid impediments or unsafe journeys. The texture and the raised area's colours differ from those of the existing sidewalks and carriageways. High vegetation (also potted) to narrow the driver's field of vision, low "pencil-like" lamps spotting the walking area, and cut-off lamps for the whole approaching and raised crossing areas complete the environment [70]. One unique raised area facilitates physically challenged users' crossing operations and reduces the implementation of detectable warning surfaces and equipment.

C Flares enable large vehicles to turn on narrow carriageways (see D) and prevent irregular parking; textures and colours differ from those of the sidewalks and carriageway.

D Cul-de-sac with a non-accessible central island (Figure 6). The approach lane is 6.00 m-wide to allow both parallel parking and low-speed travel in both directions (but the width can be reduced to 5.50 m to prevent illegal parking). A turnaround signal turns around the central island (according to reference design criteria for passenger cars provided by the Swiss Standard SN640271a); emergency vehicles can drive through thanks to the retractable bollards in the middle crossing environment.

E Bollards or vegetation to direct pedestrians to the raised area and avoid illegal parking.

F Increased walking surfaces by decreasing vehicular lanes (see D).

Figure 5. Retractable bollard, Brussels, Belgium.

Figure 6. Cul-de-sac with a mini roundabout, Vienna, Austria.

2.3. Road Closure with Narrow U-Turn Cul-de-sac

A road closure with a cul-de-sac and mini roundabout (Figure 7) is a simplified version of the previous one. It fits very narrow local roads to reduce through-traffic in a residential area. A two-lane road is closed by simply merging the sidewalks, thus creating a cul-de-sac with the following elements.

A Limit of the existing sidewalk.
B Creation of one single raised pedestrian area, as in 2.2 B.
C Bollards or vegetation to direct pedestrians to the raised area and avoid illegal parking, as in 2.2 E.
D Cul-de-sac with a narrow U-turn. Two configurations are proposed (i.e., T- and gamma-layouts). The approach carriageway is 5.50 m-wide to allow parallel parking and travel in both directions. Sidewalks can be enlarged thanks to the restricted car lanes (Figure 8). Emergency vehicles can drive through thanks to retractable bollards placed in B.

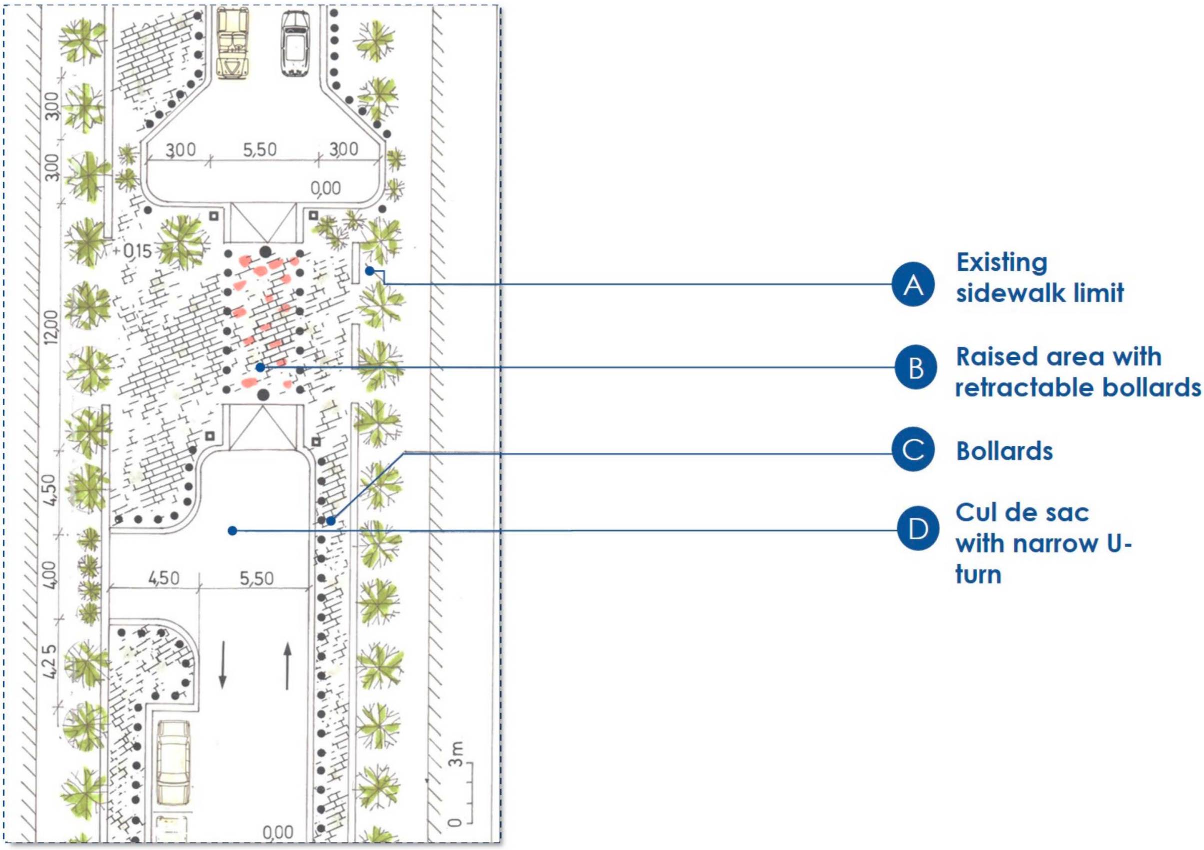

Figure 7. Road closure with a simple cul-de-sac (units in m).

Figure 8. Enlarged sidewalk, London, United Kingdom.

2.4. Three-Arm Intersection with Raised Crossing

A three-arm intersection with a raised area where pedestrians and vehicles share the road provides benefits in terms of safety and functionality (Figure 9).

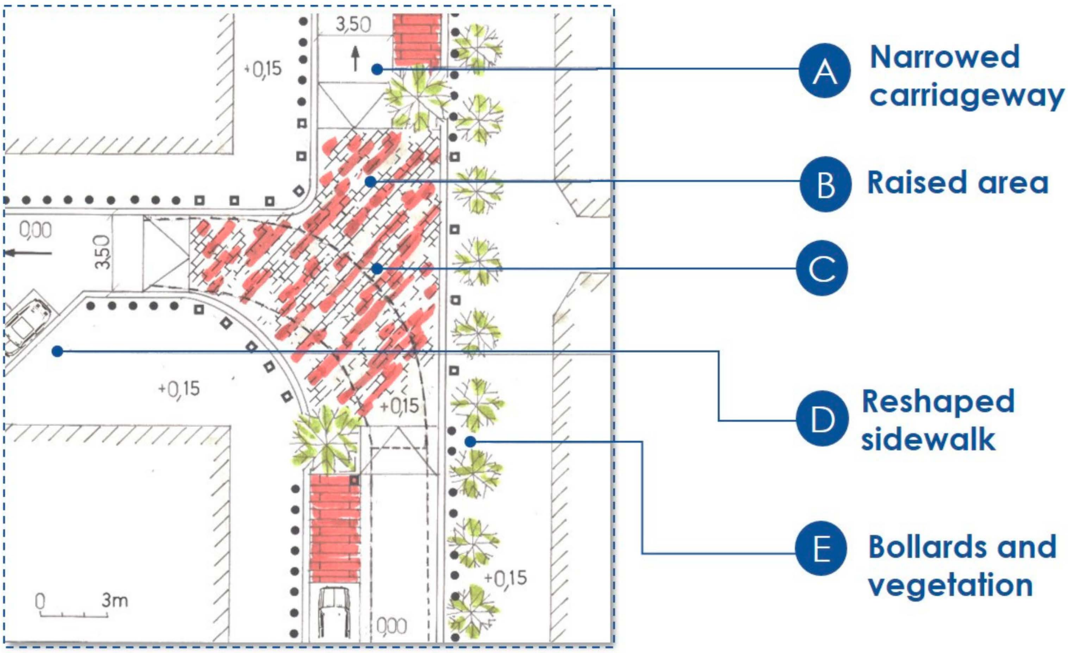

Figure 9. Three-arm intersection with raised crossing (units in m).

This layout can be designed by including the following elements:

A Narrowed carriageway for cars approaching the raised area. Stone elements (cobblestones, bollards, etc.) narrow the carriageway to 3.5 m and prevent irregular parking (Figure 10) and high vegetation (i.e., trees, also potted) warns drivers that they are approaching a conflict point. The intervention (choker or neckdown) narrows the mouth of the intersection, causing motorists to slow and encouraging pedestrians to cross at the correct location. However, it requires bicyclists to merge with traffic.

B Raised area creating a shared space among motorised and non-motorised modes, designed as in 2.2 B. Here, pedestrian traffic has the right of way and cars are "guests". To direct visually impaired pedestrians, detectable warning surfaces can be installed; in any case, colours and textures differ from those of the existing infrastructure.

C Area for large vehicle (emergency or utility ones) turning manoeuvres, designed according to the Swiss Standard SN640271a.

D Sidewalks reshaped to narrow the carriageways and parking lanes. As in the previous examples, low lighting for pedestrians and general public lighting, equipped with cut-off lamps, complement the layout.

E Bollards, vegetation, and low-lighting fixtures to direct pedestrians to cross at the safest point and avoid irregular parking (Figure 11).

Figure 10. Stone elements restricting the carriageway and/or preventing illegal parking, Barcelona, Spain.

Figure 11. Bollards and vegetation restricting the carriageway and/or preventing illegal parking, Barcelona, Spain.

2.5. Median Opening to Create a Pedestrian Refuge

A central refuge island on a zebra crossing, created by a median opening (Figure 12), reduces the car–pedestrian conflict areas. Moreover, it forces vehicles to reduce speed and breaks the crossing distance for pedestrians into two shorter legs.

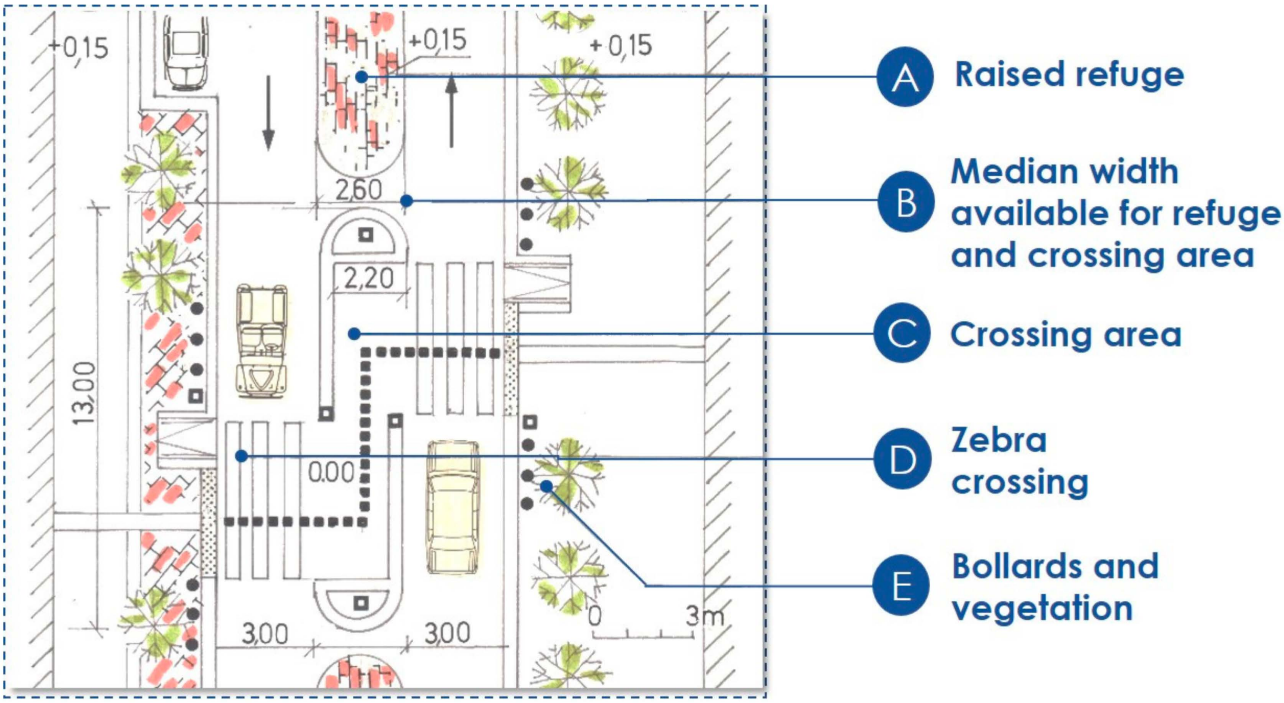

Figure 12. Median opening to create a pedestrian refuge (units in m).

This layout's main elements are:

A Central refuge for pedestrians. It divides the carriageway into two one-way lanes and enables both pedestrians and bicyclists to wait in a safe area.

B Median width available to create the crossing point with a refuge (Figure 13) and sidewalk protrusion to reduce the conflict area.

C Crossing area designed to meet universal design requirements and standards, as in 2.1 F. The refuge enables pedestrians and riders to stop and resume crossing. Drivers are alerted via warning light signals. The whole crossing area is equipped with a cut-off lighting system. For increasing pedestrians and vehicles volumes, zebra crossing can be regulated by traffic lights from the pelican crossing (i.e., the standard pedestrian crossing with traffic lights) to the toucan crossing (i.e., a crossing shared by pedestrians and cyclists with traffic lights, which modifies the crossing phase depending on the presence of the people crossing), to puffin crossing (i.e., pedestrian crossing with traffic lights on call and phase regulated by an infrared system).

D Zebra crossing equipped with a ramp for physically challenged pedestrians (typically, wheelchair users) and a step with detectable warning surfaces (i.e., the curb of the sidewalk) for the visually challenged ones. Metallic flat bollards or "bubbles" determine the centre line of the available space. The crossing approaching areas of the sidewalks are also equipped with detectable warning surfaces.

E Bollards to direct pedestrians towards the designated crossing point and to avoid jaywalking, as D in 2.1.

Figure 13. Crossing area with a pedestrian refuge, London, United Kingdom.

2.6. Chicane

By designing a sharp double bend on the carriageway (Figure 14), it is not only possible to force drivers to slow down but to create a safer crossing point and enlarge the available surface for pedestrians. The geometric layout limits bicyclists' use of the road and implies the potential loss of on-street parking lots.

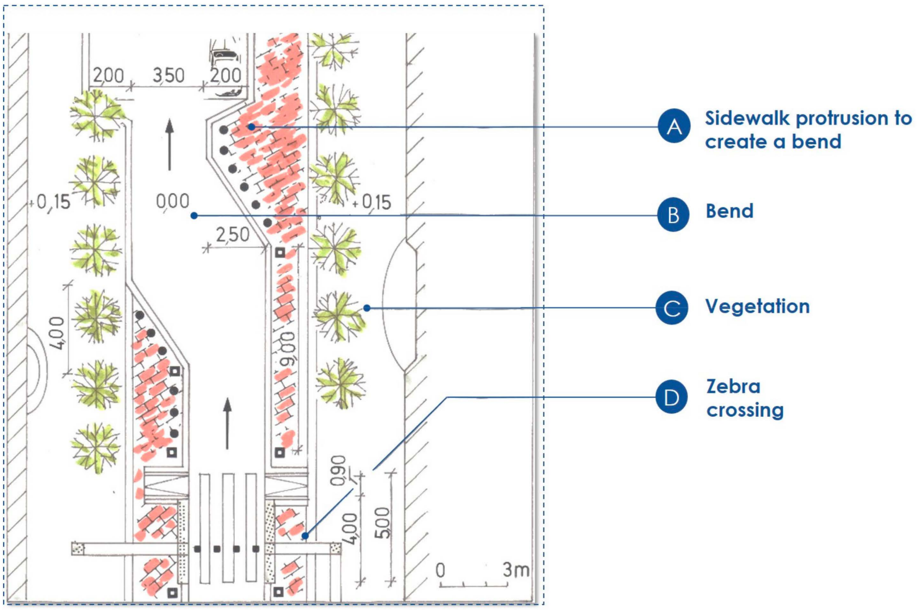

Figure 14. A chicane (units in m).

Many of the elements have already been cited in the previous examples and are resumed here as follows:

A Sidewalk protrusions to create the bends and the parking lane and reduce the crossing distance. Shaped as in 2.3D and Figure 8 with colour and texture differing from the existing infrastructures.

B Bends to narrow the carriageway and accommodate both passenger and large vehicles according to Swiss Norm SN640284. Bollards are placed to direct pedestrians towards the crossing area (Figure 15) and to avoid jaywalking and illegal parking. The crossing area can be placed at the end of the bends.

C Vegetation to shape the enlarged sidewalks into two approaching areas for crossing or to shape the bends (Figure 16).

D Zebra crossing designed as D in 2.5.

Figure 15. A chicane, London, United Kingdom.

Figure 16. A chicane with flowerbeds, San Francisco, CA, USA.

2.7. Crossing Area with Speed Humps

Simple zebras can be shaped into safer crossing areas by introducing speed humps to slow vehicular traffic (Figure 17). Speed humps are 10 cm-high and 5 m-long on average.

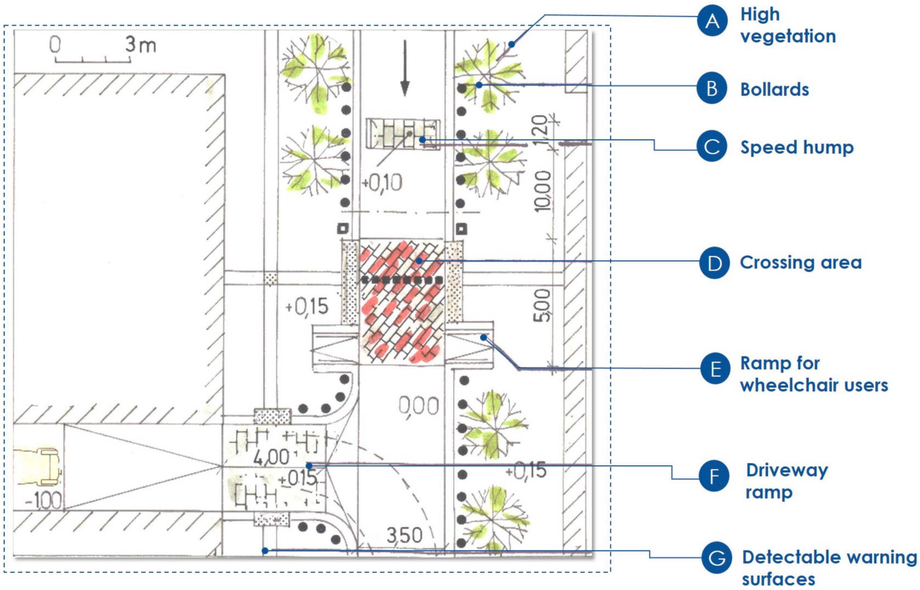

Figure 17. Crossing area with speed humps (units in m).

The main elements are:

A High vegetation to alert pedestrians and drivers of the pedestrian area. The existing vegetation can be integrated with different shapes, foliage texture, and colours of the new greenery. Typically, trees with edges or flower beds are combined, mixing perennials with deciduous trees in line with the local climate and natural conditions.

B Bollards to direct pedestrians towards the crossing area (as in 2.3 E, for example).

C Speed hump (Figure 18) with possible differing colour and texture from the carriage-way to slow down vehicular traffic ahead of the crossing area. As an alternative to speed humps, Berlin speed cushions are vertical devices that reduce passenger car speeds without interfering with mopeds and motorcycles [71], allowing large vehicles to pass unaffected. On the other hand, speed tables are longer than speed humps and flat-topped, with a height of 7–12 cm and a length of 6–7 m; they are suitable for collector streets and transit or emergency response routes.

D Crossing is designed according to the universal design criteria, as in 2.1 F.

E Ramp for wheelchair users designed according to Italian Norm 506/93.

F Driveway ramp (slope < 10%) to create a raised area and avoid grades for pedestrians (Figure 19). A change of surface colour and texture can alert pedestrians that they are approaching a conflict point. Detectable by drivers, warning surfaces and bollards (Figure 18) increase the safety level and avoid illegal parking or jaywalking.

G Detectable warning surfaces to provide path guidance.

Figure 18. Crossing area with speed humps, London, United Kingdom.

Figure 19. Driveway ramp with bollards, Brussels, Belgium.

2.8. Four-Arm Intersection with Diverter

A central raised area turns a four-arm intersection into two turning bends for vehicles with a fully walkable strip for pedestrians, which also substitutes zebras for crossing (Figure 20 represents a diagonal diverter). Traffic volume and speed are reduced, through-traffic is avoided, and the surface for pedestrians is enlarged. The elements included in this layout are:

A One-way, 3.50 m-narrowed car lane; the carriageway's remainder area is turned into sidewalks and the parking lane. Bollards and vegetation narrow the carriageway.
B Raised area (+0.15 m) shared by vehicles and pedestrians and designed as in 2.2 B.
C High vegetation (also potted) to alert drivers to the turning areas.
D Central diverter to direct vehicular traffic (Figure 21), designed according to Swiss Standard SN 640282. The diverter also avoids illegal parking near the intersection. It is equipped with retractable bollards to enable emergency and utility vehicles to pass through if need be. Different islands or curbed closures can be designed to prevent through or turning movements (e.g., diagonal, star, truncated, and forced turn measures).
E As shown in the previous layouts, a lighting system with low lamps for pedestrians and cut-off lamps for the area.
F Area for large vehicle (emergency or utility ones) turning manoeuvres, designed according to the Swiss Standard SN640271a, as in 2.4 C; note that in case of construction drawings and detailed design phases, it is recommended to use a software simulator.

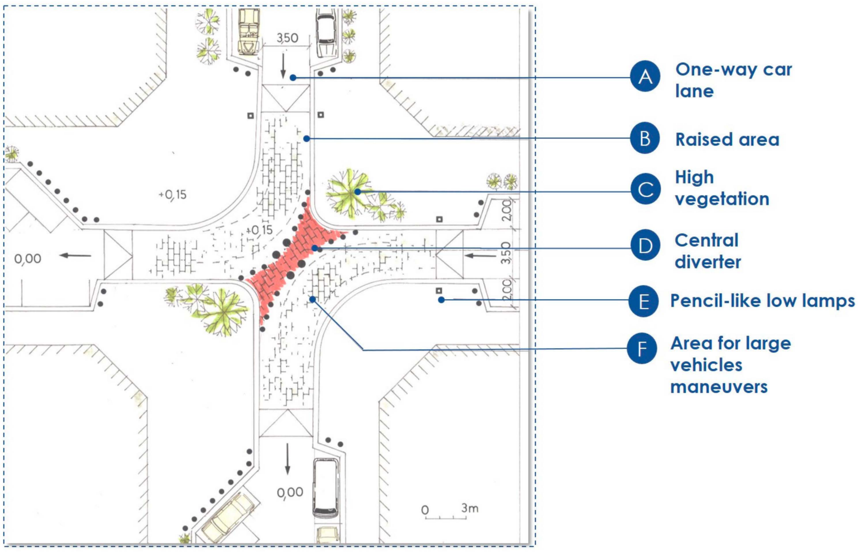

Figure 20. Raised crossing with a diverter (units in m).

Figure 21. Diverter, Vancouver, B.C., Canada.

3. Results and Discussions

Traffic calming devices should be part of an urban system uniquely identifiable by drivers and pedestrians, repeatable, and integrated with similar systems in other city areas. Under such conditions, a set of traffic calming elements can ensure its effectiveness if properly located. Table 1 summarises traffic calming warrants in regard to mobility issues. They are useful for choosing the best option, although it depends on the study area [72] and the initial vehicle and pedestrian volume [73].

Table 1. Traffic calming requirements—mobility issues.

Road Type	Pre-Scenario Motor-Vehicle Volume (veh/h/lane)	Pedestrian Volume (vol/4 h)	Before Speed Limit of Approaching Traffic (km/h)	Emergency Path	Suggested Traffic Calming Measures
Pure residential roads	up to 350	<50	50		Four-arm intersection with build-outs
	up to 150	>500	30		Road closure with cul-de-sac and mini roundabout
	up to 150	>500	30		Road closure with simple cul-de-sac
	up to 350	>500	40		Four-arm intersection with diverter
	up to 500	250–400	30		Chicane
Moderately mixedland use roads	over than 400	250–400	50		Three-arm intersection with raised crossing
	up to 550	<50	50		Median opening to create a pedestrian refuge
Collector roads	up to 550	250–400	30		Crossing area with speed humps
Key to colours	No adaptation needed	Carriageway to be adapted	Carriageway and sidewalks to be redesigned		

Vertical devices are not suitable before driveways, on approaches to intersections, on more than 8% slope branches, or where traffic calming measures would not be visible. Berlin cushions can substitute speed humps to balance the reducing speed goal and the needs of emergency vehicles. In regard to the locations type, pedestrian refuge islands and speed humps are suitable to spot location measures; diverters, speed humps, and raised tables are suited for intersections, while horizontal measures (e.g., reducing the number of lanes, carriageway narrowing, partial- or full-street closure) are suitable for roadways. With variable boundary conditions, all the tools are appropriate for streets within a district. Nevertheless, narrow-lane roads should be avoided on primary emergency vehicle routes and no-parking areas next to fire hydrants should be designed to allow fire trucks' operation.

Table 2 lists the potential impacts of traffic calming tools, focusing on the road and urban functions; the last column on noise and air pollution mitigation is assessed by considering potential benefits from improved driving styles associated with low vehicular speed (fewer accelerations and decelerations). Green boxes refer to positive or absent interaction between the measure and the investigated variable, yellow boxes refer to critical or to-be-investigated interactions between the tool and the boundary parameter, and red boxes refer to negative impacts.

Table 2. Traffic calming impacts on urban functions and the environment.

Traffic Calming Measure	Run-Off Water Management	Loss of Parking	Snow Removal Operations	Presence of Schools or Playgrounds	Noise and Air Pollution Mitigation
Four-arm intersection with build-outs	Green	Green	Green	Green	Red
Road closure with cul de sac and mini roundabout	Yellow	Yellow	Yellow	Green	Green
Road closure with simple cul de sac	Yellow	Yellow	Yellow	Green	Green
Three-arm intersection with raised crossing	Red	Green	Green	Yellow	Yellow
Median opening to create a pedestrian refuge	Green	Green	Green	Red	Red
Chicane	Green	Red	Yellow	Yellow	Yellow
Crossing area with speed humps	Yellow	Yellow	Red	Yellow	Red
Four-arm intersection with diverter	Red	Green	Yellow	Yellow	Yellow
Key to colours	Green: No interaction or interaction positively impacting		Yellow: Interaction requiring improvements or adaptation	Red: Interaction negatively impacting	

Vertical devices (i.e., speed humps or cushions) are permanent measures mainly used to reduce vehicle speed and traffic volume and to increase the users' safety. They are generally made of hot rolled asphalt that requires attention during construction because their shapes depend on manual activities. On the other hand, temporary solutions made of rubber models can be removed for winter operations. Whatever the material, Berlin speed cushions ensure good road drainage and make it easier for cyclists to pass.

Horizontal devices require more building efforts to be implemented than vertical ones and are often limited by pre-existing geometries and adjacent land uses. They differ in traffic volume and speed reduction; horizontal markings can increase their effectiveness [74]. Chicanes imply a reduction in road volume because they discourage shortcutting and through-traffic; they are not recommended on bike routes and are ineffective on low-volume roads. Curb extensions do not affect the traffic volume, increase pedestrian visibility, and prevent irregular parking at intersections. As for pedestrian refuges, their narrower section reduces crossing distance for pedestrians and causes a potential loss of parking. Barriers across the intersection (e.g., diverters and closures) force traffic to turn on adjacent streets and lengthen trips. Environmental-energy indicators highlight the negative results of traffic calming devices on high-traffic roads [75]. Both air emissions, particularly PM_{10} from diesel vehicles, and energy consumption increase; noise is a related defect in speed humping [76]. Therefore, such measures can provide environmental benefits only if they force a reduction in traffic activity, such as partial or total road closure [77]. It is difficult to value construction and maintenance costs because they depend on materials and landscaping.

Table 3 lists the geometrical and functional properties of the pedestrian infrastructure after implementing the investigated traffic calming measures. In particular, the net width of the sidewalk refers to the actual walkable space for pedestrians in Figures 1, 4, 7, 9, 12, 14, 17 and 20, and it recognises restrictions and protrusions due to curbs, urban furniture, and buildings, according to [40]. On the other hand, the pedestrian flow has been obtained according to [78], and the level of service has been obtained from the pedestrian flow characteristics in [79].

Table 3. Geometrical and functional properties of traffic calming strategies.

Traffic Calming Measure	Walking Area Net Width (m)	Flow (ped/min/m)	Level of Service
Four-arm intersection with build-outs	1.5	32	D
Road closure with cul de sac and mini roundabout	2	32	D
Road closure with simple cul de sac	2	32	D
Three-arm intersection with raised crossing	4.5	40	D
Median opening to create a pedestrian refuge	3	32	D
Chicane	1.5	16	B
Crossing area with speed humps	2	23	C
Four-arm intersection with diverter	9.5	32	D

Finally, Table 4 summarises the direct (D) and indirect (I) effects of the investigated measures.

Table 4. Direct and indirect effects of the investigated traffic calming measures.

Traffic Calming Measure	Effects					
	Reduction in Through-Traffic	Speed Reduction	Clarity of the Residential Function	Pedestrians' Safety	Environmental Benefits	Appeal to Correctness
Speed hump	I	D			D	D
Berlin cushion	I	D	D	D	D	D
Raised crossing	I	D	D		D	D
Sidewalk protrusion	I	D		D	D	D
Choker	I	D		D	D	D
Chicane	I	D			D	D
Narrowed carriageway	I	D	D	D	D	D
Diverter	D	D	D		D	D
Cul de sac	D	D	D	D	D	D
Zebra crossing		D	D	D	U	D
Toucan crossing		D		D	I	D
Pelican crossing		D		D	I	D
Puffin crossing		D		D	I	D
Pedestrian refuge				D		
Shared area	I	D	D		D	D
Raised crossing	I	D	D	D	D	D

Note: I = indirect; D = direct.

To conclude, the eight scenarios comply with the design criteria reported in the literature sources cited in Section 1.1 [41–45], and the use of materials, vegetation, urban furniture, and public lighting is conceived to go beyond the mere meeting of the safety requirements and create fully liveable environments (i.e., pedestrian realms with what was postulated in [50–55]). Being "easy pieces", they can be enforced in any regulatory tools [58,59] and smoothly introduced in the most advanced design concepts for urban repurposing [60–62], eventually deploying their higher potential to enhance the quality of life of the communities they are designed for [66–68].

4. Concluding Remarks

Traffic calming measures offer solutions for traffic concerns and ensure a safe environment for vulnerable users (e.g., motorists, bicyclists, pedestrians, and residents on neighbourhood streets). Several strategies are currently used, providing examples of physical obstacles that divert traffic horizontally or vertically, reduce lane or carriageway width, or reduce or avoid conflict points between motor vehicles and light ones or vulnerable users.

Nevertheless, in consolidated areas, such measures can conflict with surrounding constraints that cannot be overlooked. Therefore, a multicriteria approach should consider the input data about road type, current traffic volume and speed, and traffic composition without overlooking emergency vehicles, snowploughing, and stormwater drainage. The before–after analysis should predict the transportation effects and the environmental consequences of increased noise and emissions, construction and maintenance works and costs, aesthetics, and boundary constraints. The ongoing process to convert the transportation systems to electric vehicles gives opportunities to air quality improvement even in traffic calming areas. Indeed, environmental disadvantages from vertical tools (e.g., increased noise and pollution) can be prevented.

A further issue to consider is the regulatory support that enables the enforcement of traffic calming. Although, as already observed, grey and scientific literature abound, the crucial element in appropriate design and enforcing traffic calming is the availability of specifications and standards and their framing within sustainable mobility policies. Although standards are available in many European countries, they are still missing in some others, e.g., Italy. This slackens the pace of full-scale enforcement of traffic calming as shared and replicated practice at the urban level, even when regulatory tools that include it among the active tools to improve life quality are in place, typically the Sustainable Urban Mobility Plans. This discrepancy calls for a supranational regulation to overcome differences, pave the way for its full enforcement, and create consolidated practice everywhere in Europe.

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