

Article

Sustainable Complete Streets Design Criteria and Case Study in Naples, Italy

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Abstract: Background: A growing number of communities are re-discovering the value of their streets as important public spaces for many aspects of daily life, creating the need for a transformation in the quality of those streets. An emerging concept of ‘complete streets’ is to accommodate all users of the transportation system. Methods: In this paper, we present sustainable complete streets design criteria that integrate complete streets by adding socio-environmental design criteria related to the aesthetics, environment, liveability, and safety. To help set priorities, identify the street design features, and create intuitive multimodal networks throughout the city, we have defined a list of the general and specific criteria to be addressed for sustainable complete streets. Results: The proposed design criteria provide a street network with improvements in its aesthetics, to recover the historical urban character and realize historical area planning goals; the environment, to increase the permeable surfaces, reduce the heat island effect, and to absorb traffic-related air pollution; the liveability, to create a public space destination in the urban landscape; and safety, to improve the safety of all road users. The design scenarios proposed in the study were conceived to help practitioners to consider these context-based uses and design accordingly by gaining knowledge from past experiences to benefit future projects. Conclusions: The case study of the urban rehabilitation of the “Mostra d’Oltremare” area and its cultural and architectural assets in Naples, Italy, highlights the practical application of the proposed criteria and the possibility of using these criteria in other urban contexts.

Keywords: urban streets; aesthetics; environment; liveability; safety; vulnerable road users



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1. Introduction

A growing number of communities are re-discovering the value of their streets as important public spaces for many aspects of daily life, thus creating the need for a transformation in the quality of streets. People need streets that are safe to cross or walk along, that offer places to meet, and have a vibrant mix of retail. Additionally, more people must be able to walk and ride bicycles in their neighbourhoods, as communities pursue more sustainable development and lifestyle patterns. As a result, an increasing number of cities are looking at modifying the way they design their streets. Furthermore, there is a need for flexibility in applying the current design guidelines and the use of creative design in addressing site-specific project needs [1]. In North America, an emerging concept is to accommodate all users of the transportation system, be they pedestrians, cyclists, public transit users, or motor vehicle drivers and passengers, a concept that has been variously labelled ‘complete streets’ and ‘walkable thoroughfares’ [2–9]. The European Commission has been actively supporting sustainable urban mobility planning (SUMP) over the last years. Its core goal is to improve the accessibility and quality of life by achieving a shift towards sustainable mobility [10]. Recently, several cities have prepared guidelines as

well as sets of best practices to support and encourage the tailoring of designs towards the creation of a community that promotes safety, connectivity, and attractiveness through a transportation network that accommodates all modes, all ages, and all abilities (i.e., Alexandria, [11]; Denver, [12]; Edmonton, [13]; London, [14]; Montgomery, [15]). Despite the rapid increase in the interest in the complete streets design criteria and the European Commission's support in sustainable mobility planning, only a few European cities have provided transportation engineers, city planners, urban designers, and architects with policies incorporating such an approach to address the change from the past vehicle-focused roadway design philosophy to user-focused street planning.

At the same time as communities re-discover their streets as public spaces and complete streets design principles, they are also realizing that street design significantly impacts the transport and land use system and overall community sustainability. It has long been understood that how we design our communities impacts the demand for travel and the choice of the travel mode [16,17]. In turn, the resultant travel demand impacts non-renewable energy consumption, pollutant and greenhouse gas emissions, obesity, congestion, collisions, and other factors that impact community [18]. Previous research found an association between promoting active and sustainable mobility (i.e., walking and cycling) with physical and mental well-being [19]. In a "complete street" intervention in Salt Lake City (Utah), a street was renovated to be more supportive of active travel by pedestrians, cyclists, and transit riders. This renovation included five new rail stops, improved sidewalks, bike lanes, and landscaping. After the intervention, residents who started using the complete street were found to have increased their physical activity and reduced their body mass indexes [20]. Another research carried out in Madrid found a 15% reduction of the nitrogen dioxide pollution in just three months after establishing low emission zones [10].

Road safety also benefits from encouraging active modes of transport. The European Traffic Safety Council [21] declared that 9500 people are killed on average on urban roads in the EU. Only in 2017, the people killed in the urban area accounted for 38% of all road deaths. Roughly 70% of those killed on urban roads were vulnerable road users: 39% were pedestrians, 12% were cyclists and 19% were powered-two-wheeler (PTW) riders, whereas car occupants accounted for 25% of all road deaths. Road regenerations and sustainable mobility measures can further contribute to tackling a city's road safety problems and help to reach the EU target of halving the road deaths and serious injuries by 2030 [22].

Therefore, it is of critical importance that all street designs and street reconstruction projects follow complete streets design principles. The need to promote the healthy and safer development of cities has become even more urgent with the outbreak of the COVID-19 pandemic, stressing the importance for policymakers and urban planners to shift their focus to more user-oriented planning and urban renewal [23].

To address these emerging issues, the purpose of this paper is two-fold: (1) to present sustainable complete streets design criteria that integrate the concept of complete streets with the principles of socio-environmental design criteria related to the aesthetics, environment, liveability, and safety; and (2) to present an Italian case study to highlight the practical application of these sets of criteria, which taken together we will label as 'sustainable complete streets' design criteria. The design scenarios that will be provided in this paper have the purpose of showing how the sustainable design criteria may vary by street type and represent possible alternatives to challenge the primary accommodation of automobiles, offering equally safe and comfortable mobility among all users.

Providing practical applications in a series of problematic locations, the paper also aims to seek out opportunities to design and retrofit streets in one of the most complex urban contexts in Naples. The sustainable complete streets design criteria can be employed in retrofits of urban areas and help to enhance the overall community sustainability.

2. Literature Review

The sustainable complete streets are streets that aim to reflect and accommodate all users' needs while incorporating sustainable elements including street trees, landscaping, and environmental and social perspectives, so that people walking, cycling, taking transit, and scooting have the same access to safe and comfortable streets as those driving a motor vehicle. Furthermore, the term sustainable also refers to the mobility provision of active transportation infrastructures ensuring a connective network of transit options, reducing car trips, and promoting healthier active transport choices.

Aesthetics, environment, liveability, and safety are all part of the very complex land use and transport system. The quality of urban life—the space designed for pedestrians, cyclists, and bus traffic together with that of private and commercial vehicles—is one of the major urban street design issues of our time. Collectively, we refer to it as aesthetics or functional ambience [24].

Historically, streets and public squares were designed for symbolic representations of government and/or monarchy power: see for example Washington, D.C.; Paris, France; and Naples, Italy. Streets were defined by building facades and facing activities. Architectural design defined the quality of a building and an urban landscape surrounding it. With most cities now built, the emerging practise has been to search for open spaces to retrofit, thereby helping to improve the quality and ambience of city life with an enhanced sense of place, benefiting local commuters, businesses, and property owners [14].

Today, an increased population and traffic density require streets as a means of connection between city destinations. This evolution in a street's functional ambience, from a local support space to a connector of disparate non-local functions, has frustrated local planning and built-environment design processes. Moreover, the volume and speed of traffic has increased in areas historically designed for much lower traffic demands, eroding the intrinsic benefits of restorative, resting and/or green spaces on streets.

Streets have also needed to deal with the context within which they are located. Since 1986, the United Nations have introduced the principle of incorporating environmental and sustainable practices [25] to space planning. Identified by the term eco-design [26], this approach assumes that any size and shape of the project also impacts the landscape and environment, other than just the society. Thus, it places attention on an economic, optimized, proportionate, and essential design aimed at a particular utility, use or purpose. Moreover, when talking about the design of more sustainable communities, public space considerations often dominate, and lead to urban liveability design discussions on population density, mobility, infrastructure, and green space [27]. Ensuring healthy lives and making cities and human settlements inclusive, safe, resilient, and sustainable are targets that also include road safety (e.g., targets 3.6 and 11.2 [28]). Lowering the number of road user casualties is the key to improve the overall performance of the transport system and to meet the citizens' and companies' needs and expectations. Furthermore, more than half of fatalities are among vulnerable road users (VRUs) such as the riders of mopeds, pedestrians, cyclists, and motorcyclists, who represent an important challenge for road safety [29]. Undesirable road features may represent potential hazards for road users, contributing to future crashes. According to a preventive and systemic approach to road safety, road inspections are essential to identify treatments to improve the safety of the existing network before crashes happen [30–33]. However, safety should be considered in all design stages, and road safety audits should form an integral part of the design process during the draft design, detailed design, and pre-opening and early operation stages [30]. Among the factors contributing to road crashes, speeding or travelling at inappropriate speeds for the road environment, the prevailing weather, light, traffic and road conditions, are considered the most critical [34–39]. Higher speed reduces the available reaction time for drivers and, therefore, creates a greater crash risk. Moreover, a high collision speed is an aggravating factor in all crashes. An increased collision speed is associated with more severe consequences in terms of injury and the material damage. To reduce the volume of auto trips and the exposure to a crash risk, the SMARTer Growth Neighbourhood design [27,40,41] has

been used in the urban area as a system that facilitates lower auto volumes, lower vehicle speeds, and a lower conflict frequency between a pedestrian/cyclist/vehicle.

The risk of pedestrian crashes also increases when the crosswalk locations are not in line with the desired pedestrian paths [32] or are not appropriate for the road alignment [42,43]. Parking, cycle facilities, and bus stops may create a significant increase in the pedestrian risk. In some circumstances, parking is allowed very close to the crosswalk, thus creating conflicts between pedestrians and vehicles. Pedestrian accessibility is another important safety issue, including for mothers with baby strollers, seniors with walking aids, wheelchair users, visually impaired users, and tourists with luggage. Crosswalks that are not designed for accessibility have been associated with an increased number in people crossing away from a crosswalk, and not using the adjacent sidewalks at all, further degrading safety [33]. Recently, to encourage a healthy and environmentally sustainable lifestyle, the promotion of bicycle use has been embraced by urban and transport planners; however, there is evidence of an increasing crash risk for cyclists rather than for motorized vehicles [43–45], mainly due to infrastructure characteristics leading to a higher number of conflicts between cyclists and other road users. Cyclists are legitimate users of the roadway and an integral part of the transportation system so that the facilities for cyclists, preferably separated and continuous cycle tracks on both sides of the street, should be considered an integral part of any proper road planning process and network design [46].

An important safety issue is the sight distance at urban intersections, cycle crossings, crosswalks, and even along sidewalks, as there are often obstacles that obstruct the views and distract road users. To warn motorists of hazards, and to regulate and guide traffic (e.g., performing such functions as assigning the right-of-way), traffic control devices are extensively used. Their effectiveness is proportional to their clarity and visibility at any time of the day, in all seasons, and through each weather condition, whereas their deficiencies have been found to be influencing drivers' unsafe behaviours [47,48], contributing to a considerable proportion of crashes. Adequate lighting can improve visibility during the night-time [42,49–51] and this is particularly important to improve the pedestrian/cyclist visibility on or beside roads, as well as on off-road paths, and the visibility of other road users for pedestrians and cyclists. Previous research results encourage the use of light-emitting diode (LED) sources during the night-time as they are effective for increasing drivers' attention [52,53].

3. Methodology

3.1. General Issues

Efforts to transform streets into sustainable complete streets (or from traffic-based to accessibility-based designs) face resistance at times, from both professional communities of traffic engineers and planners and from policy makers and the general public who feel new designs do nothing more than reduce automobile access [9]. However, re-thinking and re-shaping streets may have a significant impact on street functionality providing evidence that streets can do more than just move cars. The proposed sustainable complete streets design criteria aim to provide a transport system in line with the contemporary social, economic, and environmental priorities of urban mobility and access, including care in providing quality and comfortable (i.e., liveable) land uses. The aesthetics, environment, liveability, and safety are all invoked to re-think the streets and to re-design them to meet changing preferences and future needs. The implementation of such design principles may help in [8–15,25–27]:

- Reducing traffic crashes and injuries, of both motorized and vulnerable road users;
- Reducing motorized traffic volume and speed;
- Increasing pedestrian, cyclist, and public transport traffic volume;
- Improving the quality of the urban landscape space, for example, its aesthetics and functional ambience;
- Recovering the urban character lost in a historical evolution due to a lack of conscious, coordinated urban planning;

- Creating a homogeneous road environment with regards to the choice of materials, colours, lighting, and treatment of green spaces;
- Increasing ‘green space’ opportunities for pedestrians and cyclists to stop, shop, and socialize;
- Reducing non-renewable energy use and its associated air pollution emissions;
- Reducing nuisances due to traffic noise and urban heat island effects.

Nevertheless, the selection of the required actions to shift ordinary streets into streets that serve multiple purposes and multiple modes of transportation is not easy. Based on a literature review and on the most recent guidelines [11–15] that support and encourage tailoring designs towards sustainability and complete streets principles, the general and specific criteria to be addressed are proposed, identified, and briefly explained in Table 1.

Table 1. Synthesis of the sustainable complete streets design criteria.

General Criteria (Section #)	Specific Criteria	Integration with Complete Streets Criteria
Aesthetics (3.2)	A1 Enhancement of the urban environment to recover historical urban character and realize historical area planning goals	Full integration between street design and the planning for redevelopment of the public space
	A2 Integration of materials, colours, lighting, and treatment of green spaces	Sustainable approach to integrate the street design and the built environment
	A3 Durable materials	Requirements for the use of durable pavements, markings, signs, lightings, and street furniture to reduce the unpleasantness caused by deterioration during its life cycle
Environment (3.3)	E1 Eco-design	Life Cycle Design and Life Cycle Assessment of building products
	E2 Planting and trees	Use of green space to form a natural filter and buffer from pollutant gases, dust, and noise as well as to reduce urban heat islands
	E3 Reduction in traffic-related air pollution and noise	Strengthening of the community system design approach to reduce auto trips and promote healthier active transport choices
Liveability (3.4)	L1 Usability and comfort of the public outdoor space system	Attention to the functional and environmental design aspects of public space to ensure that end user and lifecycle impacts are addressed with a view toward sustainability
	L2 Creation of a public space destination in the urban landscape which affects activities and social relations	Coordination between urban planners, landscape architects, and transportation engineers in developing the design of the street as a public space destination in the urban landscape
Safety (3.5)	S1 Road safety inspections	Introduction of formal road safety inspections of the existing network
	S2 Road safety audits	Introduction of formal road safety audit of all plans and designs prior to construction
	S3 SMARTer Growth Neighbourhood design	Safe system design of community land use and transport to reduce auto use and speeding
	S4 Safe pedestrian routes and crosswalks	Specific criteria to provide a comprehensive, safe pedestrian route network
	S5 Safe cycle routes and crossings	Specific criteria to provide a comprehensive, safe, and continuous cycle route network
	S6 Sight distance	Explicit consideration of visibility from the perspective of all roadway users
	S7 Transit and pedestrian accessibility	Link between accessibility and safety
	S8 Traffic control devices	High-performance traffic control devices as explicit safety criterion (e.g., roundabouts)
	S9 Lighting	Use of high-performance lighting as explicit safety criterion (e.g., solar power LEDs)

Practical applications of the sustainable complete streets design criteria are presented with reference to the Mostra project in Italy (Section 4). A survey was made among engineers with relevant expertise in the field of road design and transportation planning and architects with similar experience to understand how they would evaluate the practical application of the sustainable complete streets design criteria in the four specific redesign locations presented in the case study.

In Figure 1 we identify the main steps towards the implementation of sustainable complete streets design criteria.

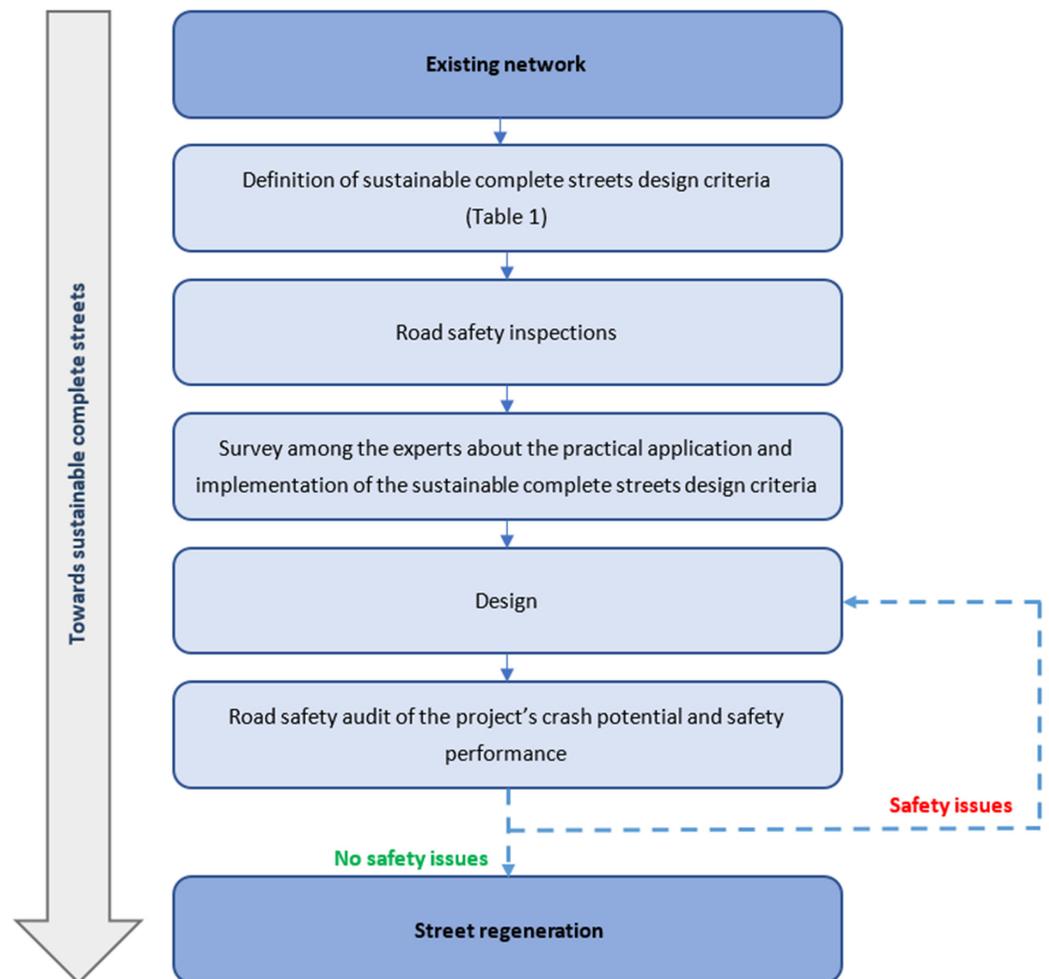


Figure 1. Methodology workflow.

Compared to the existing design criteria discussed in Section 2, the major novelties of the proposed criteria are the integration of sustainability and the complete streets criteria as well as the definition of specific criteria to provide a street network adapted to contemporary requirements for community sustainability, quality of life, and vulnerable road user safety, while providing for traditional urban mobility, the historic context, and efficiency.

3.2. Aesthetics

Planning the redevelopment of public space must begin with defining the principles that will relate to the quality of the open and public areas. Indeed, the aesthetics reflect the quality of urban life and includes the space designed for pedestrians, cyclists, and bus traffic together with that of private and commercial vehicles in a harmonious way [13,14]. The rehabilitation of the public space, including complete street re-design, provides an opportunity for a sustainability-oriented, eco-design approach to project design. For example, it might include the materials selection to maximize the accessibility, sustainability, durability, drainage, and aesthetic appropriateness to be integrated with colours, lighting, green space and ecology in the project [12,13]. However, steps toward realizing this opportunity must deal with the problems that the unruly urban phenomenon of traffic proliferation has generated. No literature demonstrating this eco-design retrofit approach has been found.

3.3. Environment

Environmental criteria describe the relative importance of maximising the positive environmental impacts and minimising the negative environmental impacts in the design of a street [14,25]. The eco-design aims to control the design and assessment of impacts over the entire life cycle of the design 'product'. This eco-design concept of sustainability-based design principles leads to an integration of policy, inputs, and production to ensure green procurement, the durability of materials, green construction, the choice of urban furniture, and high-performance lighting [26].

Green space can be used to form a natural barrier to pollutant gases, dust, and noise as well as to reduce urban heat islands. Additionally, through the choice of appropriate materials it is possible to reduce urban heat effects, such as choosing no-fines paving, and rough or smooth functional strips. As another example, through the road surface material treatment, results can be achieved toward speed reduction for safety, energy and resource savings, in both the up-front and long-term benefits [12,13,26]. Moreover, the reduction in maintenance costs (typically over half of a project's life-cycle costs), can be achieved by careful resource choices made at the design phase of the project [54].

The factors of environmental and architectural integrity of use provide an urban space with different degrees of aesthetic quality. A perception of environmental comfort can be attributed to the perceived factors and can shape positive behaviour. In this sense, the aesthetic quality of the space must be seen increasingly as an integration between perceptual factors, signage, graphic communication and environmental comfort combined with vegetation. Aesthetic integrity represents how well a design solution's appearance and use behaviour can integrate with the multiple functions of an urban space.

3.4. Liveability

Impacting the quality of life, liveability refers to the significance of a street to its users as a social or recreational destination [9,14]. The characteristics of the broader reference context is a common concern of the community's architectural image at both the city-wide and local-area scales, which intersect via local sustainability-oriented designs. For example, consider in broader contexts the relationship between buildings and their environment characterized by the presence of historically established features and activities. Urban planners and landscape architects must work with transportation engineers in developing the design of a street as a public space destination in the urban landscape, not just as a thoroughfare, including how its physical elements affect the activities and social relations in those two (local and city-wide) contexts.

These two non-engineering disciplines rightfully pay attention to public space in terms of [24]:

- Ambience, i.e., the conditions of usability, comfort and safety of the public outdoor space system, including its quantity and quality of green amenities; its environmental and ecological function; and its coherent configuration;
- Function, highlighting the added value of high environmental performance in terms of efficiency, functionality, maintenance, durability and recyclability, including a reduction in energy consumption at the urban and building scale; reductions in air, water, noise and visual pollution; and the mitigation of impacts generated by infrastructure systems.

The attention to these functional and environmental design aspects of public space helps to ensure that user and lifecycle impacts are addressed with a view toward sustainability—pedestrians and cyclists; transit; parking; innovative technologies; renewable energy sources; and the integration of explicit (e.g., signs) and implicit (e.g., surface colouration) information and communications technologies.

Beyond public space as a destination, road (re-)designs must also consider other fundamental functions, including that of moving people. Road network rehabilitation is an opportunity for a wider urban and environmental regeneration, but only where it is possible to have an integrated, team approach within the fields of environment, engineering, and planning [9,13,15]. It means an integrated vision of design measures aimed at improving the

quality of urban life, developing approaches that encourage public–private partnerships and involving a wider variety of stakeholders in the process of urban transformation than being only historically engaged [55]. A diverse team for these projects in which complexity reigns is a strategic and success-critical resource to be cherished and supported. In this regard, it is strategically important to identify the most appropriate regulatory and administrative frameworks to implement the configured actions, by not only checking their compatibility, but also proposing innovative and advanced solutions that best meet well-defined community values and visions.

3.5. Safety

To make cities inclusive, safe, resilient and sustainable, safe transportation facilities for all users and mobility provisions have a pivotal role. Safety means lowering the number of road user casualties, improving the overall performance of the transport system and meeting citizens' and companies' needs and expectations. A sustainable complete street intervention should also include a consideration of the pedestrian priority, bicycle priority, and transit priority, when designing the new shape of a street or designing a future street.

3.5.1. Road Safety Inspection

To improve the safety of the existing network, the sustainable complete streets design criteria require routine safety inspections of the road network to identify potential hazards for all road users. These are assessed by measuring the risk in relation to road features that may lead to future crashes, so that the remedial treatments may be implemented before crashes happen according to a preventive and systemic approach to road safety [30–34]. Traditionally, safety improvements have been realised only at hotspots after a high number of crashes have occurred [49,56–59]. If only the hotspots are treated, many locations that can be expected to experience crashes in the future will remain untreated. Waiting for crashes to occur to warrant action carries a high price, as vulnerable road user crashes tend to be severe. Furthermore, vulnerable road user crashes are generally widespread in the road network and under-reported, thus creating difficulties in hotspot identification based only on crash statistics.

3.5.2. Road Safety Audits

The designers should investigate how the road environment is perceived, and ultimately utilized, by each user group—pedestrians, cyclists, and motorists—and within each user group, namely, seniors, children, persons with disabilities, and the drivers of powered two-wheelers, trucks, and cars. Several issues must be considered to ensure a safe design and it is not possible to define specific rules which guarantee a safe design. Standards are an important starting point with any road design and a designer should be familiar with the relevant standards, attempt to comply with them and be aware of where any standard cannot be achieved.

However, road designers will agree that standards do not guarantee safety, for the following reasons:

- Standards are often a minimum requirement and combining a series of minimums can leave no room for error, either on the part of the designer, the builder or the final users;
- Some situations require specific expert judgements, which might not be covered by the standards;
- Individual road elements, designed to standard, may be quite safe in isolation but may be unsafe when combined with other standard elements;
- Driver errors, which contribute to 93% of all crashes [49], are bound to happen.

A road safety audit is a formal examination of a future road or traffic project in which an independent, qualified team reports on the project's crash potential and safety performance [56]. Especially in urban areas, where there are often several competing objectives, a road safety audit ensures that safety is not overlooked in satisfying the many competing and complex objectives.

For urban area design processes, recommended principles to promote safer road use are provided below.

3.5.3. Smarter Growth Neighbourhood Design

Key issues of the SMARTer Growth Neighbourhood design are:

- Roundabouts to reduce conflicts and crashes [60–62];
- Traffic calming to lower speeds and short-cutting on local streets, and improve ped/bike safety;
- Continuous off-road ped/bike paths, such that biking across a neighbourhood is faster than driving;
- Fewer road lanes of narrower width, with lower speed limits to address the crossing distance and safety;
- Comprehensive bicycle and pedestrian route networks in accord with active travel demand and desire lines, integrated with compact, connected, and coordinated mixed land uses;
- Keeping major mobility roads to perimeter one-way couplets containing service commercial blocks and controlled by roundabouts to reduce the crossing risk and speeds;
- Interspersed public, open, green, restorative spaces throughout, such that no dwelling is longer than a one-minute walk away from public open space, with a major central, car-free piazza that promotes both local and community-wide social interaction;
- Convenient, affordable, and accessible, high-capacity public transit connecting this neighbourhood with major civic destinations.

3.5.4. Pedestrian Crosswalks

Crosswalk locations must be evaluated in relation to the road alignment and the desired pedestrian paths and a special emphasis should be given to the interaction with parking, bicycle facilities, and bus stops along major roads. The use of bulb-outs to reduce the interaction between pedestrians, bicycles, bus stops, and parked vehicles is strongly encouraged, such as that in the Dutch bicycle design guidelines [46]. Mid-block crosswalks located after bus stops may induce pedestrians to cross in front of the stopped bus, with a detrimental safety effect due to the visibility of pedestrians obscured by the bus.

Vehicles turning into and out of driveways may conflict with pedestrians walking along roadways. These conflicts can be reduced by a consideration of pedestrians during the planning stages of a project, and by consolidating existing driveways. Removed driveways, or the consolidation of driveways, can create space for other uses such as seating opportunities that might support adjacent businesses, or planting areas that provide buffers between vehicles and pedestrians.

In the case of wider roads, the presence of an adequate median 'block' and/or refuge should be carefully considered. Painted crosswalks aligned with pedestrian desire lines encourage pedestrians to cross within the crosswalk, where drivers are more likely to expect them.

3.5.5. Pedestrian Accessibility

Designers should consider the needs of all road users looking in detail at the accessibility needs in each local context; therefore, the important accessibility issues to consider include [55,63]:

- The presence and slope of curb ramps (e.g., crosswalks without ramps or with ramps with an excessive grade are inaccessible for wheelchairs and baby carriages);
- The height of the curbs separating sidewalks from roads (e.g., an excessive height poses significant problems of accessibility—falls and trips—to older people moving between parking spaces and the sidewalk);
- Rumble-strips and tactile-strips for visually-impaired pedestrians (e.g., ramps without preceding 'warning' strips are a significant hazard for blind people);
- The accessibility of median breaks (e.g., inaccessible breaks make a refuge ineffective).

3.5.6. Cycle Routes

The context of the road for a bicycle facility is a key element that should be considered in a design. Cyclists should be provided with a complete and connected bicycle network, without any horizontal or vertical obstructions (either temporary or permanent) along the facilities, which offers safe routes to destinations. The riding surface should be smooth, stable, free of debris, and with adequate drainage. In many cities, retrofitting to meet complete street principles for bicycles is a difficult problem. A variety of innovative and effective design solutions is emerging in complete streets design guides, including road diets, parallel 'bicycle-friendly' streets, and protected, buffered bicycle lanes [46,64–67].

3.5.7. Sight Distance

An insufficient sight distance increases the crash risk by reducing reaction times and stopping distances. An adequate sight distance provides drivers with sufficient time to identify and appropriately react to all elements of the road environment, including other road users and hazards [68]. Designers should evaluate the visibility from the perspective of all roadway users, especially children and persons in wheelchairs, who may be lower to the ground. The sight lines between all users should be free from obstructions. Typical obstructions the designer must deal with carefully include lighting and traffic signal posts, traffic control and bus stop posts, traffic signal controller kiosks, utility kiosks, newspaper kiosks, litter and recycling kiosks, and trees.

3.5.8. Traffic Control Devices

High-quality road signs and road markings are crucial to support drivers [55]. As regards the road signs, the use of fluoro-reflective, micro-prismatic sheets is recommended. Fluoro-reflective, micro-prismatic sheeting allows for [69,70]:

- Greater daytime visibility;
- Greater night-time visibility;
- Greater visibility in the presence of light pollution (e.g., fog);
- Optimum angularity;
- Excellent visibility at wide entrance and observation angles;
- Greater visibility in critical conditions, such as in rain, snow, cloudy weather, at dawn, and at dusk.

As regards the markings, it is recommended to use high performance markings such as cold-hardened materials, which provide for enhanced safety through effective daylight and night-time visibility, as measured by their luminance coefficient under diffuse illumination, and by retro-reflectivity (i.e., their ability to reflect light from a vehicle's headlights back to a driver's eye) [71].

3.5.9. Lighting

Optimal lighting allows for improved perception and visibility of pedestrians, the mutual sighting of vehicles, the right perception of the road environment, and the visibility of potential hazards.

To obtain the best safety and energy performances, the use of LEDs is recommended. They are solid-state devices that produce blue light in combination with phosphors that convert some of the blue light to yellow light, with the resulting mixture appearing white. LEDs allow for very long-rated lives and a good lumen maintenance. Some of the main advantages of LEDs are a more uniform light distribution; lack of warm-up time; energy savings; reduction in the frequency of maintenance; directional light; reduced light pollution; environment-friendly characteristics; and breakage and vibration resistance [72].

An important safety requirement is to provide an adequate pedestrian visibility distance at crosswalks, defined as the distance at which a driver can see a pedestrian well enough to be able to respond appropriately to the pedestrian's presence. The greater the visibility distance, the more time a driver will have to react to the pedestrian before a conflict occurs [52]. In some instances, energy-saving, automated crosswalk lighting can

cause hazards if triggered too late after a pedestrian is present. Overly delayed crosswalk lighting activation can restrict the visibility of crossing pedestrians; therefore, the timing of lighting activation is a safety-critical design issue.

4. Case Study

4.1. Overview

The Campania Region in Italy was chosen as part of the EU's Regional Operational Programme framework to identify major projects in the fields of sustainable transport, environment, infrastructure, and tourism. On 28 March 2011, Resolution 122 of the Regional Council established several major projects in the city of Naples, including one project related to the urban rehabilitation of the "Mostra d'Oltremare" area and its cultural and architectural assets. The design of this urban rehabilitation has employed the principles and criteria of sustainably complete streets design, as summarized below.

The study area is characterised by the presence of important attractors: buildings of significant architectural value in the Overseas Exhibition, the university, and in sports facilities. Taken together with the major regional road and railway networks, this area is one of Naples main activity centres. Its urban development occurred mainly in the late 1920s and 1930s, and in 1936 Mussolini awarded Naples the Triennial Overseas Exhibition, in Italian referred to as the "Mostra d'Oltremare", or locally known as Mostra. Typical of Mussolini-period architecture, Mostra contains a monumental centre, and was intended to be representative of the historical centre of a modern-era city. Mostra is characterized by wide open spatial and environmental qualities, thanks to the purposeful design of green and open spaces, which were intended to connect the two historical centres (i.e., Mostra and historical Naples). It remains of nostalgic importance for city life as the main centre for trade shows and sports events, as well as for the presence of numerous national research institutes, university departments, and government offices.

The urban context within which Mostra is situated (Figure 2) is complex, where over the past 70 years Naples has been impacted by a series of civic policy decisions that, in recent decades, have created major road traffic congestion problems. Only in recent years has Naples started to consider ways to close gaps in its pedestrian and bicycle networks. Moreover, the contemporary design and civic policies have evolved to embrace the dichotomies of everyday life constantly experienced in Naples, including private auto use versus public transit, accessibility versus mobility, private versus public spaces, and day versus night use. Design criteria were required to rehabilitate this pluralistic area, with its modern economy based heavily on international tourism that 'never sleeps'.



Figure 2. Study area.

The Mostra environmental and architectural rehabilitation was aimed at recovering its urban character in the context of its historical significance, while addressing its growing

circulation, access, and aesthetics needs, including changes to the streetscape and networks. Specific problems that the project had to address related to:

- Urban streets with the features of rural roads (D1 in Figures 2, 3a and 4a);
- The layouts of urban spaces with poor consideration of the environment, aesthetics, and liveability (D2 in Figures 2, 5a and 6a);
- Inadequate and discontinuous pedestrian and bicycle paths (D3 in Figures 2, 7a and 8a);
- Pedestrian and bicycle routes in the layout of roads for motorized vehicles (D4 in Figures 2, 9a and 10a).

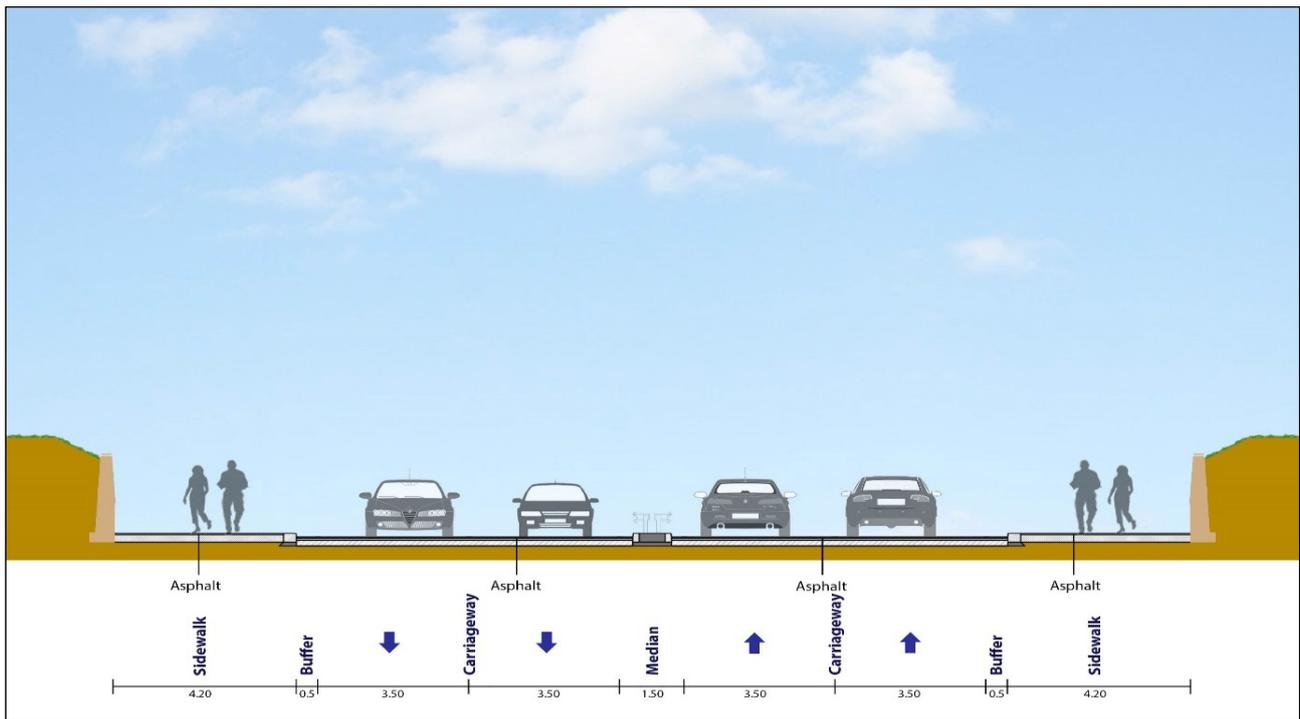


(a) Existing scenario.

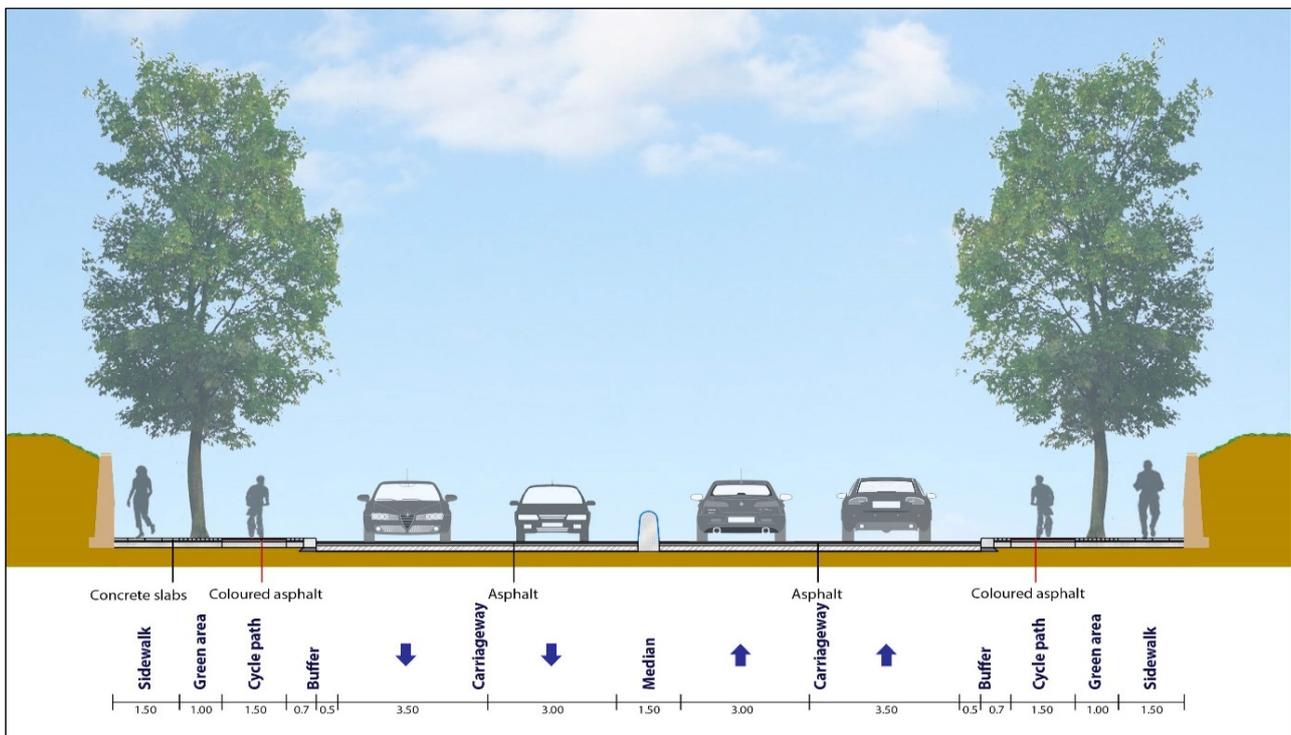


(b) Design scenario.

Figure 3. Urban street with the features of a rural road: example of design improvement.



(a) Existing scenario.



(b) Design scenario.

Figure 4. Urban street with features of a rural road: existing (a) and design (b) cross section.

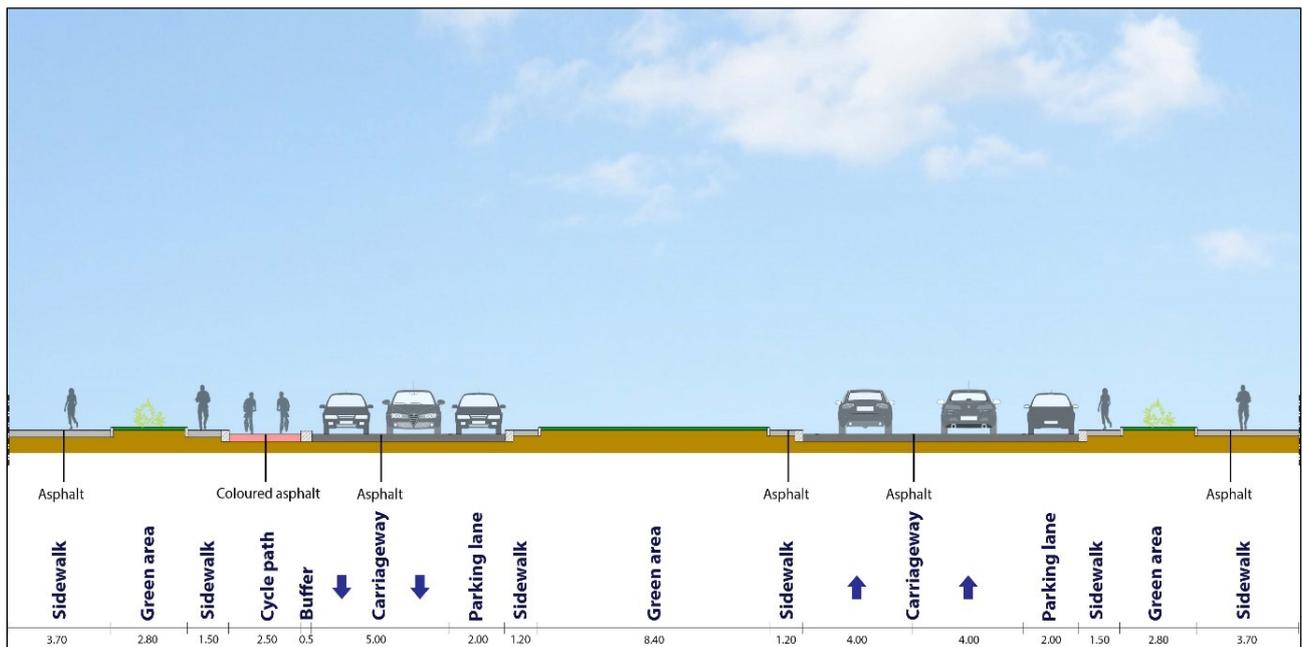


(a) Existing scenario.

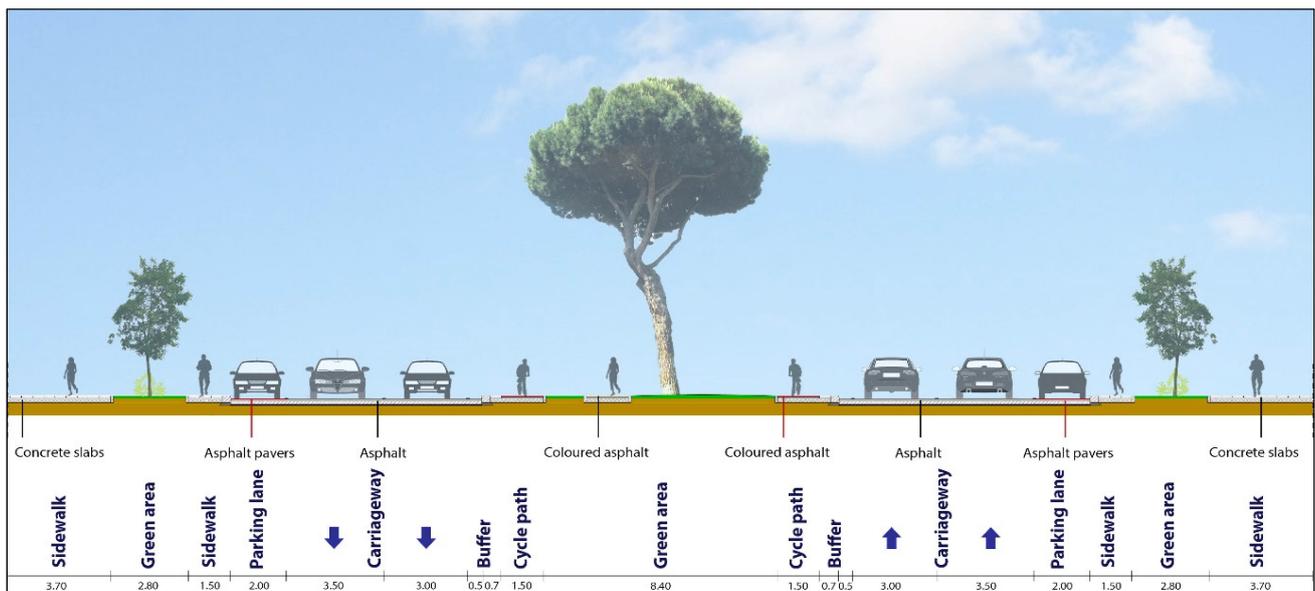


(b) Design scenario.

Figure 5. Layout of urban space with poor consideration of environment, aesthetics, and liveability: example of design improvement.



(a) Existing scenario.



(b) Design scenario.

Figure 6. Layout of urban space with poor consideration of environment, aesthetics, and liveability: existing (a) and design (b) cross section.

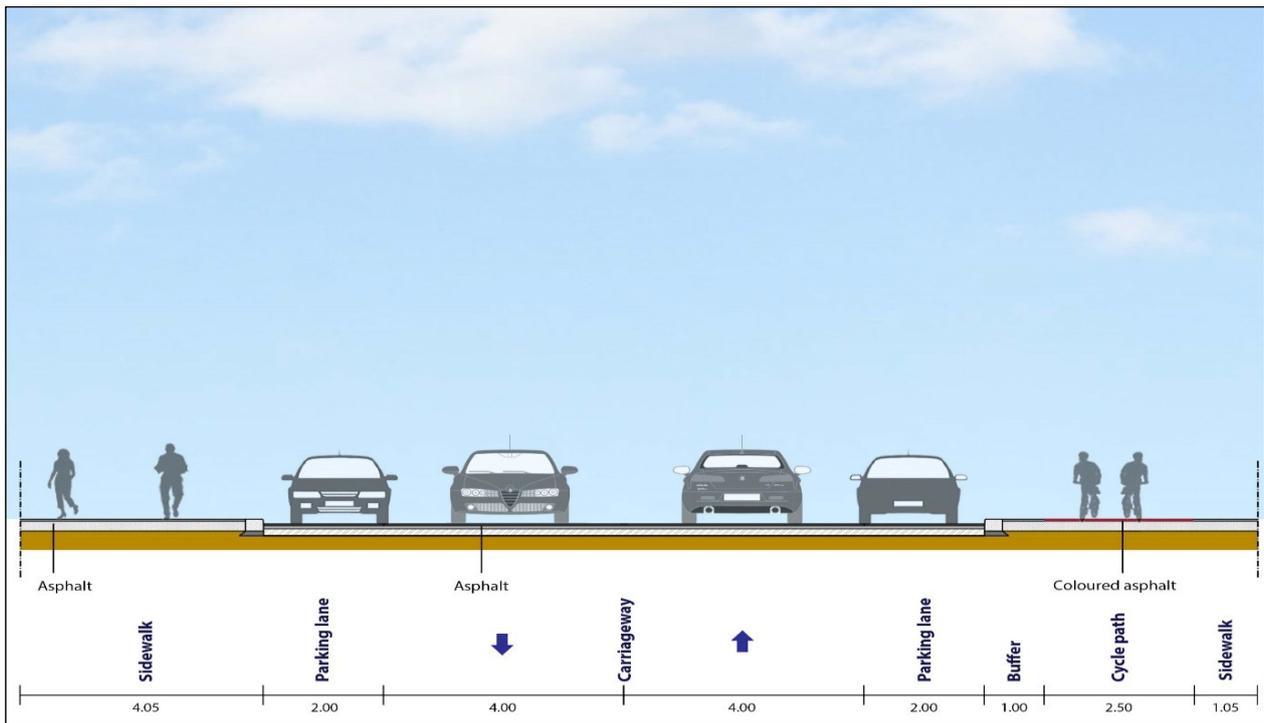


(a) Existing scenario.

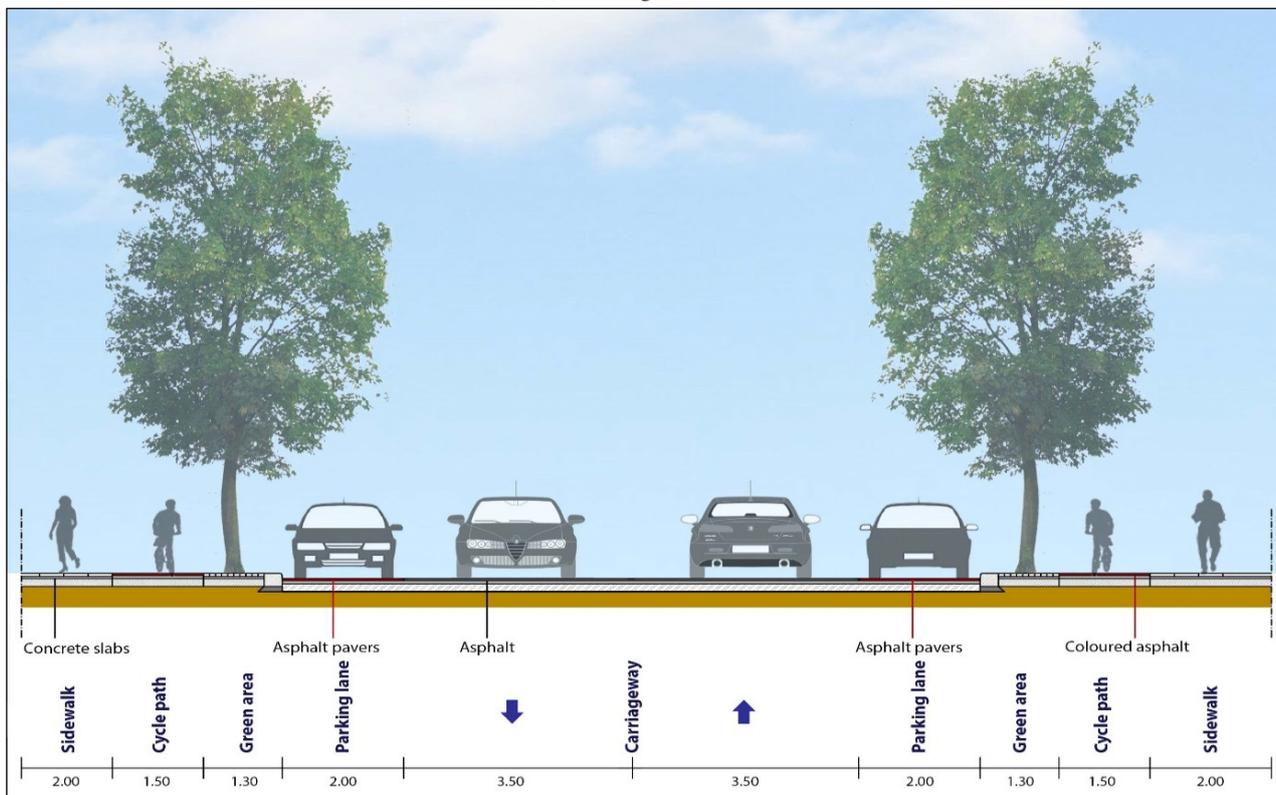


(b) Design scenario.

Figure 7. Inadequate and discontinuous pedestrian and bicycle paths: example of design improvement.



(a) Existing scenario.



(b) Design scenario.

Figure 8. Inadequate and discontinuous pedestrian and bicycle paths: existing (a) and design (b) cross section.

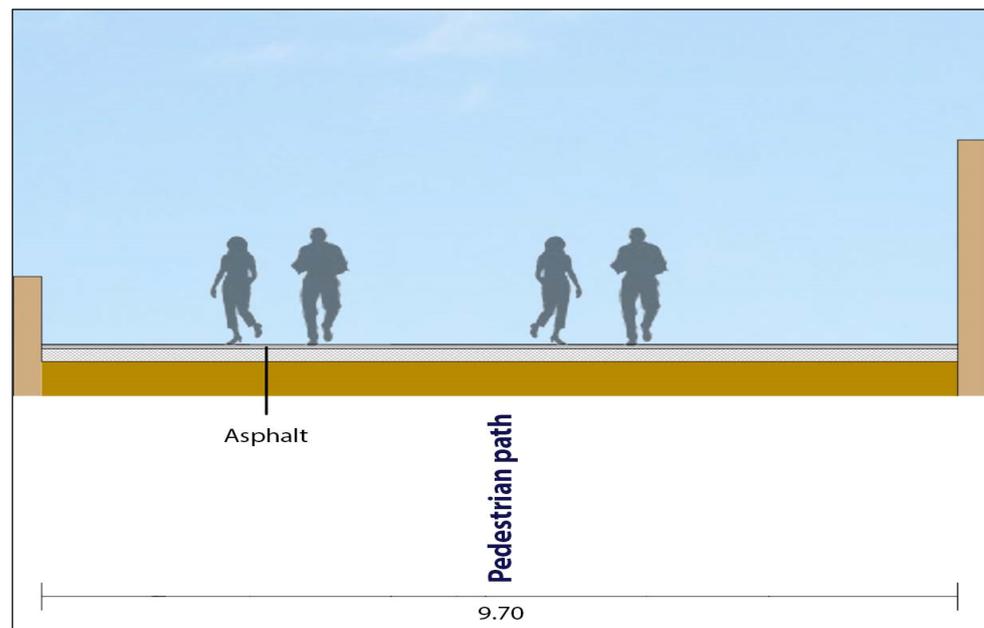


(a) Existing scenario.

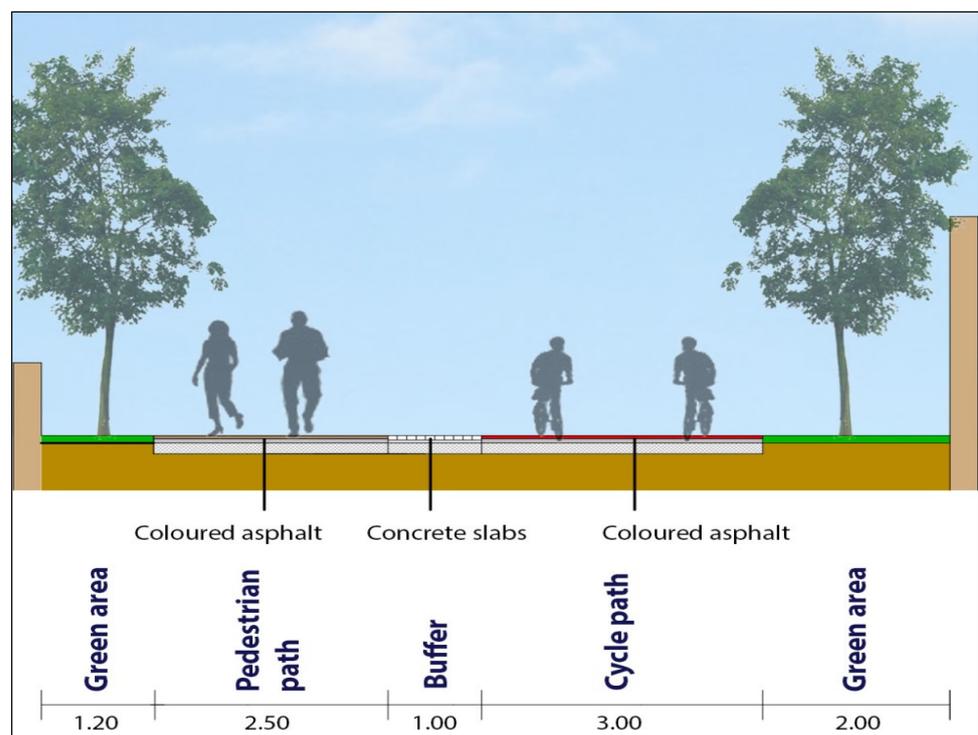


(b) Design scenario.

Figure 9. Pedestrian and bicycle routes in the layout of roads for motorized vehicles: example of design improvement.



(a) Existing scenario.



(b) Design scenario.

Figure 10. Pedestrian and bicycle routes in the layout of roads for motorized vehicles: existing (a) and design (b) cross section.

Practical application of the sustainable complete streets design criteria is presented with reference to four specific designs of the Mostra project which are aimed at solving the issues presented above. To understand how independent experts would evaluate in each case study the application of the sustainable complete streets design criteria reported in Table 1, a survey was made among engineers with relevant expertise in the field of road design and transportation planning and architects with similar experience. The main experts' opinions were considered to re-shape the four locations. In Table 2 we reported

a synthesis of the specific criteria, whose implementation was suggested by the experts, and that we were able to introduce in the designs of the four case studies depending on the available section space.

Table 2. Sustainable complete streets design criteria.

General Criteria	Specific Criteria	Design 1	Design 2	Design 3	Design 4
Aesthetics	A1 Enhancement of the urban environment to recover historical urban character and realize historical area planning goals	✓	✓		✓
	A2 Integration of materials, colours, lighting, and treatment of green spaces	✓	✓	✓	✓
	A3 Durable materials	✓	✓	✓	
Environment	E1 Eco-design	✓	✓	✓	✓
	E2 Planting and trees	✓	✓	✓	✓
	E3 Reduction in traffic-related air pollution and noise	✓	✓	✓	✓
Liveability	L1 Usability, comfort and safety of the public outdoor space system		✓	✓	✓
	L2 Creation of a public space destination in the urban landscape which affects activities and social relations		✓		✓
Safety	S1 Road safety inspections	✓	✓	✓	✓
	S2 Road safety audits	✓	✓	✓	✓
	S3 Fused grid neighbourhood pattern	✓	✓	✓	✓
	S4 Safe pedestrian routes and crosswalks	✓	✓	✓	✓
	S5 Safe cycle routes and crossings	✓	✓	✓	✓
	S6 Sight distance		✓	✓	
	S7 Transit and pedestrian accessibility		✓	✓	
	S8 Traffic control devices	✓	✓		
	S9 Lighting	✓	✓	✓	✓

4.2. Design 1—Urban Streets with the Features of Rural Roads

The rural character (Figures 3a and 4a) of some streets in Mostra have a significant impact on its liveability. They encourage high speeds, discourage pedestrian and bicycle traffic, and generally dampen human-scale activities. To recover the urban character and improve access and visibility to the entire Mostra area, the design principles were built on a homogeneous choice of materials, colours, lighting and treatment of green spaces, including (Figures 3b and 4b):

- The steel median safety barrier was replaced with a blue colour concrete median barrier with a rounded shape (criterion A1, see Table 1);
- Pedestrian crossings with white zebra stripes were embedded in a red colour surface with printed bituminous concrete appearing as brick pavers (criteria S3, S4 and S8);
- The uneven and potholed pavement was replaced with an even, antiskid surface (criteria A1, A3, and E1);
- The carriageways without markings were marked with high-performance cold-hardened road markings delineating 3.50 m wide traffic lanes (criteria A3, S3, and S8);
- Both sides of the road had one-way separated bicycle lanes installed (criteria A2, E1, E2, E3, S3, S5, and S9), with these features:
 - Raised from the street and flush with the sidewalk,
 - Width equal to 1.50 m,
 - Red colour bituminous concrete surface,
 - A 0.70 m buffer from the street via a basalt curb and concrete square slabs,
 - A 1.00 m buffer from the sidewalks made by concrete square slabs, trees with regular spacing, and lighting poles with LED sources;

- Continuous and accessible sidewalks 1.50 m wide were installed (criteria S3 and S5);
- The existing, obstructive advertising signs were removed from sidewalks (criteria A1 and A2).

4.3. Design 2—Inadequate Layout

Viale di Augusto, the most important street in the Mostra area, is characterised by a layout with poor consideration of the environment, aesthetics, and liveability (Figures 5a and 6a). Its wide median is not used by pedestrians or cyclists, and its aesthetic quality is very poor. Moreover, the historical palms have died, and car parking is allowed in the median, creating dangerous conflicts between the through-traffic and people crossing the street to reach their parked vehicles. At some point in the past, a separate two-way bicycle lane had been installed in one carriageway, creating an abnormal-width carriageway of two 2.25 m lanes (plus a 0.50 m shoulder). Most importantly, the bicycle lane had been used more by pedestrians and parents with strollers due to inadequate alternatives and obstructions in historical sidewalk areas (e.g., parked cars, scooters, and street furniture). To solve these issues, a combination of measures was designed (Figures 5b and 6b), including:

- The median was completely redesigned with new trees (indigenous and hardy species) and pedestrian and bicycle paths (criteria A1, A2, E2, E3, S3, S4, and S5);
- In the median, a continuous pedestrian route was created, with central plazas and benches at regular intervals (criteria L1 and L2);
- In the median, one-way separated bicycle lanes were introduced, flush with the sidewalk, 1.50 m wide, with a red colour bituminous concrete surface, and a 0.70 m buffer from the street (criterion S5);
- Parking in the median was removed (criterion S3);
- The former counter-flow bicycle lane was removed (criterion L1);
- Parallel parking was introduced in the nearside with a different surface, i.e., a red colour surface with printed bituminous concrete appearing as brick pavers (criteria A3 and E1);
- Bulb-outs were introduced in all the pedestrian crossings (criteria S4 and S6);
- Lighting poles with LED sources were employed (criteria L2 and S9);
- Antiskid surfaces were added (criteria A3 and E1);
- High-performance cold-hardened road markings were specified, delineating 3.50 m wide outer lanes (where buses are expected) and 3.00 m wide inner lanes (criteria A3, S3, and S8);
- On each side of the Viale, new continuous and accessible sidewalks with concrete square slabs were installed (criteria L1 and S7).

4.4. Design 3—Inadequate Pedestrian and Bicycle Paths

On another part of the road network, the Viale Kennedy, a two-way bicycle lane had been installed over the existing sidewalks, which imperilled pedestrians, and many parts of the Viale had no street trees (Figures 7a and 8a). To solve these issues, the design included (Figures 7b and 8b):

- The replacement of the existing two-way bicycle lane with one-way separated bicycle lanes on both sides (criteria L1, S3, and S5) that were flush with the sidewalk, including a 1.50 m wide, red coloured, bituminous concrete surface, separated by a 1.30 m basalt curb buffer, street trees, and LED street lights (criteria A2, E1, E2, E3, S3, S5, and S9);
- Continuous and accessible pedestrian paths 2.00 m wide (criteria S4 and S7);
- Bulb-outs in all the pedestrian crossings (criteria S4 and S6);
- Lane widths that were reduced from 4.00 m to 3.50 m (criterion S3);
- Antiskid surfaces (criteria A3 and E1);
- High-performance cold-hardened road markings (criteria A3, S3, and S8).

4.5. Design 4—Conflicts between Pedestrians, Cyclists, and Cars

In Via Claudio (Figures 9a and 10a), the design needed to address high pedestrian and bicycle flows, as the street connects the north and the south campuses of the School of Engineering at the University of Naples. It also connects the north campus with a bus stop and

the railway station. Because of its high use by vulnerable users, this street had been designated as a shared pedestrian and bicycle route closed to car traffic. However, a lack of police and physical enforcement (i.e., no self-enforcing physical barriers) had allowed the street to be historically used as a shortcutting route for auto traffic, despite having no separated sidewalks nor bicycle lanes, which has caused continuing VRU/auto conflicts (Figure 8a). A combination of countermeasures was designed, including (Figures 9b and 10b):

- The removal of the concrete pavement (criteria A1 and A2);
- The installation of green strips on both sides with grass, trees, benches, and lighting poles with LED sources (criteria E1, E2, E3, L1, L2, and S9);
- Installation of a two-way bicycle lane, flush with the sidewalk, 3.00 m wide, with a red colour bituminous concrete surface (criteria L1, L2, S3, and S5);
- Installation of a 1.00 m wide buffer between the bicycle lane and sidewalk, using concrete square slabs (criteria S3, S4, and S5);
- Installation of a 2.00 m wide coloured sidewalk (criteria S3 and S4);
- Installation of 'gateway' architectural features at its ends (criteria A1, L1, and L2).

5. Results and Discussion

The sustainable complete streets criteria were applied to intervene in a series of problematic locations in the city of Naples, Italy, to seek out opportunities to design and retrofit streets in one of the most complex urban contexts of the city. The case study presented a proposal for street regenerations towards multifunctional, smart, safe, walkable, and liveable streets. Given the legacy of planning, engineering, and infrastructure in facilitating automobile movement, the shift toward the accommodation of other transport modes is not a simple change. The scenarios reported in this paper in fact challenge the primary accommodation of automobiles. Each one was reported to provide example practices to inform how existing streets may be transformed into complete streets.

To help set priorities, identify street design features, and create intuitive multimodal networks throughout the city, a checklist was created identifying all the specific criteria. Then, a survey was made among engineers and architects with relevant expertise in the field of road safety and transport systems to understand how those experts would address the application of the criteria in the case study.

The design elements were built based on a homogeneous choice of materials, colours, lighting, and treatment of green spaces, and have a potential significant impact on the liveability of the area and its aesthetics. Indeed, previous studies have demonstrated how an improvement in the quality and ambience of city life is strongly associated with its landscaping [5,20]. Furthermore, different users' needs are considered to ensure that mobility is equally safe and comfortable for all users. The presence of parts of the streets dedicated to pedestrians and cyclists improves their access and visibility, discouraging high vehicle speeds and promoting human-scale activities.

The benefits of adopting sustainable principles in complete streets design criteria are substantial. The design of community land use and transport encourages active transportation with its health benefits for individual users and for the community. Furthermore, active transportation has environmental benefits from producing no air pollution [66]. Complete streets also have economic benefits. Safe and convenient pedestrian amenities boost foot traffic, which can increase retail sales benefiting local retailers [73].

The sustainable complete streets design criteria can be employed in the retrofits of urban areas and help to enhance overall community sustainability. The design scenarios proposed in this study were conceived to help practitioners to consider these context-based uses and design accordingly, gaining knowledge from past experiences to benefit future projects; however, not every street is intended or is suitable for the accommodation of every user mode. The complete streets design criteria have large sets of potential competing priorities, where the importance of each priority will vary depending on the street context and its role in the network [74]. Hence, the identification of the different priorities by street

type is necessary to begin to understand the trade-offs among a street's required function, its space organization, and traffic volume.

Nevertheless, a reduction in the vehicle-destined spaces is not easy to understand and digest for habitual road users. Hence, national, provincial, and municipal policies should work on public acceptance and emphasize the City's interest and investment in developing safe and accessible streets that are accommodating to multiple modes and that provide an attractive public realm that allows for safe movements. Another impediment to implement sustainable complete streets relies in the resources available that should be allocated for sidewalks, bike lanes, and other complete street elements. A deep belief is that the construction costs of sustainable complete streets projects exceed the construction costs of traditional road projects. Considering the small percentage of project budgets required to include complete street elements and the significant market fluctuation in historical project construction costs, a study carried out by the Charlotte Department of Transportation [75] concluded that the construction costs of complete streets do not necessarily represent an incremental cost compared to traditional designs.

6. Conclusions

Streets are important public spaces for many aspects of daily life and have significant effects on the liveability of a city, but road designs and functions have evolved from a local-context focus to a broader connecting focus such that they no longer consider these local contextual needs. However, the need to promote the healthy, safer, and sustainable development of cities has become even more urgent with the outbreak of the COVID-19 pandemic, stressing the importance for policymakers and urban planners to shift their focus to more user-oriented planning and urban renewal.

This paper has proposed and discussed sustainability-oriented, eco-design urban street design criteria that are meant to complement and build on the existing complete streets design criteria. Specifically, the term 'sustainably complete streets' design criteria has been coined to denote the addition of socio-environmental design criteria related to the aesthetics, environment, liveability, and safety. Compared to the existing design criteria, the major novelties of the proposed criteria are the integration of sustainability and complete streets criteria as well as the definition of specific criteria to provide a street network adapted to contemporary requirements for community sustainability, quality of life, and vulnerable road user safety, while providing for traditional urban mobility, a historical context, and efficiency. The scenarios reported in this paper provide example practices on how existing streets may be transformed into complete streets. The sustainable complete streets criteria should always be included during the planning, design, and operation of roadways by government agencies, consultants, and practitioners, when designing for future streets or regenerated streets in an area experiencing land development, when implementing a capital improvement project (i.e., the construction or reconstruction of a street, intersection, or bridge), and during maintenance treatments (i.e., resurfacing a street or conducting major work in the street). This may create an opportunity to reconsider some aspects of a street's design. The importance of considering these criteria comes early in the roadway planning and design process to identify the desired characteristics of a roadway. Street design is complex and must respond to a series of local conditions and site constraints, and to set the users' priorities, an expert judgement and coordination among the architects and engineers is paramount for making decisions for specific streets and for establishing community priorities and strategies that will harmonize the transportation system, land use, and redevelopment.

If a systematic approach is taken as advocated, the benefits will include reduced motorized traffic, a reduced energy consumption, reduced traffic noise, reduced air pollution, and increased pedestrian, bicycle, and public transport traffic and safety. At the same time, criteria are included to improve the aesthetic and liveability qualities of public and/or green spaces. This is obtained through urban design solutions for structured and consistent thematic areas aimed at a unified picture of homogeneous urban zones.

The proposed criteria look at the environmental and architectural restoration to recover urban character in respect of the historical evolution and urban planning of an area. Using a systematic and team-based approach, the design solution can create a road environment that serves both functional and local needs. The local context and architectural design principles support a homogeneous, unified approach as regards the choice of materials, colours, lighting, and treatment of the green spaces. An eco-design approach has been proposed, and special emphasis is given to planting tree species and to the implementation and increase in permeable surfaces in order to reduce the heat island effect and absorb the air pollution caused by vehicular traffic.

The case study of the urban rehabilitation of the “Mostra d’Oltremare” area and its cultural and architectural assets in Naples, Italy, highlights the practical application of these proposed criteria and the possibility of using these criteria in other urban contexts. The case study shows both how each specific criteria were applied and how the concept of sustainable complete streets can contribute to urban aesthetics, the environment, liveability, and safety.

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