

Case Report

Green Resources for Safety Improvement and Sustainable Landscape Design: The Case of a Dangerous Tehran-Dizin Road Bend

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Abstract: Improving road safety is not only reliant on engineering aspects but also on the surrounding landscape, which plays an indispensable role in drivers' visual perception. As a part of road landscapes, green areas affect road safety by screening or framing views. While vistas could be highlighted in safe spots in order for road users to enjoy their travel, in dangerous scenic points, visual attractions need to be concealed to lessen visual distractions and the risk of accidents. This study aims at optimizing road safety through sustainable landscape design in one of the dangerous Tehran–Dizin road bends to meet both road safety and environmental requirements. In doing so, cone of vision formulas have been applied to calculate measures of green landscape features so as to hide visual distractions and upgrade safety. To design such a green landscape, green resources and their characteristics have been elaborated, and native species have been suggested in plant composition, which can improve the sense of place, enhance the environment, and create a sustainable landscape. The research shows that a cone of vision could functionally be employed to increase the success of a designed green landscape, especially in situations where two-dimensional approaches are not sufficient.

Keywords: landscape; visual perception; road design; safety; landscape urban planning; resources; road safety; mobility; transportation; road accidents



Citation: Habibi, M.; Chitsazzadeh, E.; Mosavi, A. Green Resources for Safety Improvement and Sustainable Landscape Design: The Case of a Dangerous Tehran-Dizin Road Bend. *Resources* **2022**, *11*, 19. <https://doi.org/10.3390/resources11020019>

Academic Editor: Volker Beckmann

Received: 8 November 2021

Accepted: 31 January 2022

Published: 9 February 2022

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1. Introduction

It is claimed that road traffic crashes result in 2.1 million deaths and 50 million injuries all over the world annually [1]. According to the information from the statistics unit of the Legal Medicine Organization of Iran, 2,756,7 and 2,767,62 individuals, respectively, were killed and injured in traffic accidents in 2006 [2]. There are several interacting factors resulting in accidents. Thus, it is not possible to clearly determine one specific cause [3]. According to the Permanent International Association of Road Congresses (PIARC) [4], the Human–Environment–Vehicle (HEV) system provides a conceptual framework to analyze accidents, leading to contributing factors identification. Treat et al. [5] investigated data from Monroe County, Florida, USA, from 1970 to 1975, which show humans, together with two other factors, environment and vehicles, are the reason for 93% of accidents. It is witnessed that 26% of accidents occur as a consequence of both human and environment-related factors [5], making it essential to consider situations where the environment would affect human behavior and perception of the road. Consisting of natural constitutions (vegetation, geological features, falls, etc.) and built components (bridges, furniture, signs, etc.) in an immediate vicinity or far distances, road landscape forms a context that includes

an array of spaces ranging from rest areas to scenic points in order for individuals to enjoy their travel while moving from one place to another. Road landscape also takes practical, technical, and economic issues, sense of place, and site physical conditions into account to balance aesthetics, efficiency, and technology [6]. It should provide users with the possibility of predicting changes along the road as well as integrity [6]. Research shows that landscape “reading” influences the driver’s behavior, which can also affect safety [7–9]. In other words, road landscape should be easily decoded to enable users to identify the location and easily anticipate the events (traffic, pedestrian, etc.) which they may face so that they can modify their behavior accordingly [10].

Visual attraction management with respect to other landscape characteristics would raise transport networks legibility. Such a sound composition encompassing vegetation, landforms, cliffs, rivers, agricultural lands, and land divisions make up what users can see [11]. Based on the road situation, for instance, a road with scenic views in safe spots, unsightly landscapes, and dangerous spots with distracting views, it is suggested to manage drivers’ visibility in order to frame, impose restrictions on, or omit some frames from their view [12]. What landscape architects and researchers would do is to analyze visual features and conduct locational and thematic evaluations with the effect of suggesting proper landscape solutions.

Current research has been derived from the first comprehensive road landscape research, entitled “Road Landscape Master Plan Project in Iran”, whose output comprises worldwide surveys, regulations, and guidelines on beautification, safety, and vegetation. The primary objective of this paper is to optimize safety levels via road landscape design in dangerous spots, with a focus on green resources so as to serve both people and the roadside environment. The scale of the research is restricted to one dangerous bend, and plant composition has been planned for this area. What is not considered in the study is psychological consequences and changes in road users’ behavior after the application of the sustainable landscape design. Drivers’ behavior examination in reality or based on driving simulations has been left for future studies.

2. Literature Review

Literature reveals some analysis of road safety in relation to landscape design. Dhar-masena and Edirisooriya [13] focused on landscape spatial characteristics, particularly solidity and degree of enclosure and scale of the space in Sri Lanka. Analysis was based on recorded accident data and a live recording of a driving experience in identified black spots. The research demonstrates that variation in both the high and low profile of enclosure is minimum in the study areas, leading to monotony and, finally, drivers’ low performance. Another paper investigated 10 highways located in Shandong province in China. Introducing a new concept of revegetation design for highway roadsides and median green belts, the study aims to reduce drivers’ visual fatigue and the following serious consequences. Based on the theory of dynamic vision, formulas are presented to compute the stake numbers of setting or removing green belts and the maximum length of green belts according to the requirements of landscape and safety [14]. Some manuals and reports could also be found that concentrate on the role of landscape designers in the safety analysis process [15], determining the correlation between landscape and safety [16]. Regarding visual tools, one scholar has worked on the application of a cone of vision and isovist, a flat geometric shape that resembles the field of view, to enhance the use of plan drawing representation [17]. Here, the exact use of the cone of vision and the implication of its mathematical calculations in landscape design leaves a critical gap in knowledge.

Studies have examined the relationship between road landscape and driving behavior with driving simulators [18–20]. One study aims to analyze drivers’ perceptions and experiences of a metal crash barrier on a broad/narrow road with a crash barrier/no crash barrier via a driving simulator [21]. Results show higher speeds on wider roads and on roads with crash barriers. Considering three Swedish landscape types (open, forested, and varied), another paper accumulates questionnaires and simulator measurement data. It

concludes that in open landscapes, drivers drove faster, and they did not drive close to the centerline while they experienced less stress [22]. Driving performance has also been discussed by Calvi [23], based on a 44-participant driving simulation to investigate the effects of roadside trees. Findings indicate that compared to the situation where there are no trees on the roadside, drivers remarkably reduce their speed and move toward the centerline of the road when trees are in the adjacent landscape and nearer to the edge of the road. Vegetation along a greenway should also be taken into account. How planting matches the surrounding landscape and arouses interest in order to boost preference and perceived restorativeness is another important matter [24]. In this regard, driving simulator scenarios focus on the effect of clear zone size and surrounding vegetation on drivers' behavior, which could additionally enhance clear zone design practices and thus roadway safety [25].

Research on vegetation, safety, and the environment have also been conducted. Main Roads Western Australia [26] considers vegetation as an alternative together with built walls and fences, earth bunds, temporary visual screens, and acoustic barriers or noise walls to screen views where a potential visual distraction occurs within the drivers' field of view. It was highlighted that visual screens must be designed in a way to meet all safety considerations, provide an effective level of screening, minimize maintenance requirements, and provide a cost-effective solution for the site conditions. Another effort was made across the United States to systematically assess public preferences for built and natural features in urban freeway roadsides. Results show that drivers most preferred settings which have tree plantings that screen adjacent land uses [27]. This can be endorsed by previous studies by Kaplan et al. [28,29], stating that people show a big preference for scenes with vegetation rather than scenes with man-made structures. Between 2004 and 2011, a survey was carried out in Poland using road accident statistical analyses which include environmental factors such as driving into a tree, hitting an animal, rainfall, snowfall, blinding sun, and strong gusts of wind. Findings illustrate that roadside vegetation positively affects road safety in many ways, while it can pose a danger to road users if it is not properly designed and located [30]. Positive effects of road vegetation are not only restricted to curbing accidents but also related to environmental benefits entailing wind velocities, soil stabilization, water quality and infiltration, and biodiversity [31,32]. Numerous other roles include the provision of habitats for plants and animals, buffering landscape from noise, dust, light, and other pollutants, and improving aesthetics [33].

In line with what was mentioned, a sustainable landscape could reduce the effects of sun, wind, and pollutants. It can also be effective in flood management through plant water uptake and water infiltration [34]. A sustainable landscape is also claimed to be "low impact, low maintenance, low resource use and frequency low-cost landscaping that fits each particular site and climate, virtually taking care of itself" [35]. To create sustainable landscapes, Hitchmough [36] mentioned some key attributes for plants specifically being fitted to the landscape that are manageable in the long term, attractive and meaningful to local people, and reflect the character of the place. The U.S. Environmental Protection Agency [37] has identified principles comprising of using regionally native plants for landscaping and selecting plants in a manner that conserves water and controls soil erosion, which is applicable in landscape design seeking to be sustainable [38]. On a city scale, sustainable landscape design principles change into high efficiency of land use, the rationality of landscape materials and engineering technology applications, building a perfect ecosystem, and emphasis on maintenance and management [39]. A number of approaches can be found towards landscape sustainability, but there is a consensus on three key aspects: there is no right solution to create a sustainable landscape every time, proposals must be contextually responsive and specific, it not only creates green spaces but benefits both humans and ecosystems simultaneously [40]. In this way, research on sustainable landscape design has followed different strategies such as green ecological landscape design [41], an eco-control system for sustainable landscape design [42], and minimized costs based on the landscape ecology theory [43].

In Iran, the first step of studying road landscape traces back to 1991 when Pirnia pointed to geographical, commercial, intangible, and cultural factors which have influenced road landscapes since bygone eras [44]. Another historical study has been conducted which highlights how ancient roads affected urban and regional development [45]. As far as the environment is concerned, contemporary research mostly focuses on environmental degradation and adverse effects of road construction on natural landscapes [46] and road landscape green areas design and vegetation [47]. Safety issues have scarcely been studied in relation to landscape. Existing literature consists of the very first manual focusing on only the characteristics of vegetation layers which should be avoided in plant selection because they can decrease the safety level [48], and it also discusses road components namely barriers, panels, and walls which could act as a safety booster [49,50]. What seems to be missing in all studies conducted in Iran is considering soft and hard road features and their measures in landscape design based on road safety conditions.

3. Materials and Methods

3.1. Study Area

Tehran–Dizin road, a 60-km mountainous road, is located in the heights of central Alborz. The road begins from the Lashgarak–Lavasan road, the study area, and passes residential and recreational areas, reaching Dizin defile at the end (Figure 1). The Jajrud River and Alborz Mountains are considered two major natural attractions along this winding road.

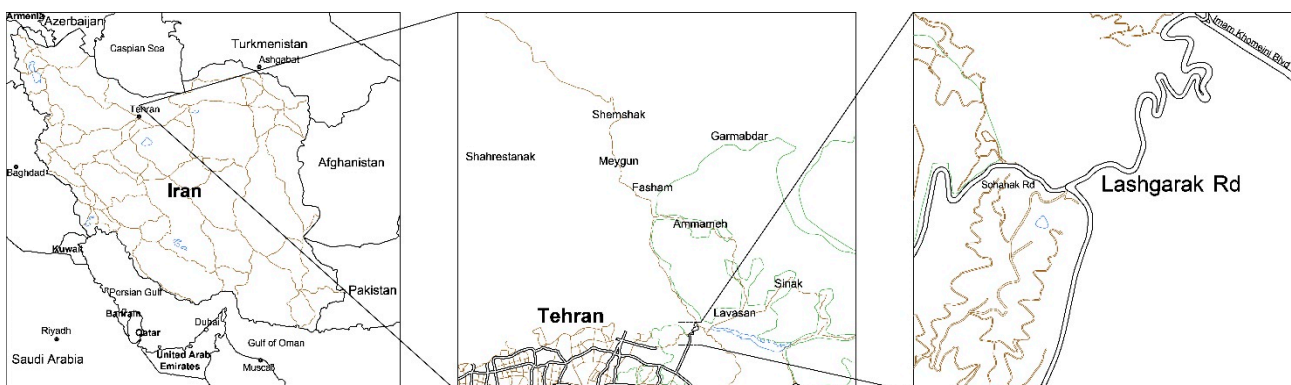


Figure 1. Road location in three scales, Iran, Tehran, Lashgarak Road.

The area which has been surveyed is located in the very first 11 km of Tehran–Dizin road. Having passed 10 successive bends (Figure 2), users would descend from 1850 m high to 1690. The dangerous bend is at 1806 m high, which is 60 m higher than the lowest part. What can be observed in this spot are panoramic views of mountains from northwest to southeast, as well as residential areas (Figure 3).

3.2. Methodology Analysis

Based on the flowchart (Figure 4), the adopted steps in this research are as follows: in the first step, a field survey and observations were conducted so that researchers became acquainted with the context of the study area, scenic views, and the field of vision of road users. Afterwards, library research was carried out to form a comprehensive literature review on the topic and methods used in the calculation of sight distance and road object dimensions. Having studied the current method and based on a knowledge gap in this field, researchers suggested cone of vision formulas to determine the size of sight obstruction. To maintain sustainability in landscape design, a palette of native plants was selected, which are finally presented in a plan and section.



Figure 2. Successive bends and location of the study area.



Figure 3. Drivers' view and bend sequences in six different frames: (a) first view, (b) second view, (c) third view, (d) fourth view, (e) fifth view, (f) sixth view.

3.2.1. Sight Triangle

As a conventional method, the use of sight triangles can be witnessed in past experiments. Among first practices, intersection sight distance design is presented in The American Association of State Highway and Transportation Officials (AASHTO) Green Book, which considers "intersection sight distance to be adequate when drivers at or approaching an intersection have an unobstructed view of the entire intersection and of sufficient lengths of the intersecting highways to permit the drivers to anticipate and avoid potential collisions" [51]. The sight triangle method has further been suggested to avoid accidents, particularly at junctions where vehicles are moving in intersecting roads. For instance, sight triangle equations and calculations were introduced in a retrofit setting in order to address safety and operational concerns and to design facilities and site plans, which will reduce the risk of drivers and cyclists [52]. This notion is a non-barrier surface, which is formed by each road extension along the drivers' line of sight. In this right triangle, the hypotenuse is drawn from one vehicle to the other one, both of which are moving toward the junction. Two other sides of the triangle would be along the main and secondary roads, crossing each other at the junction [53].

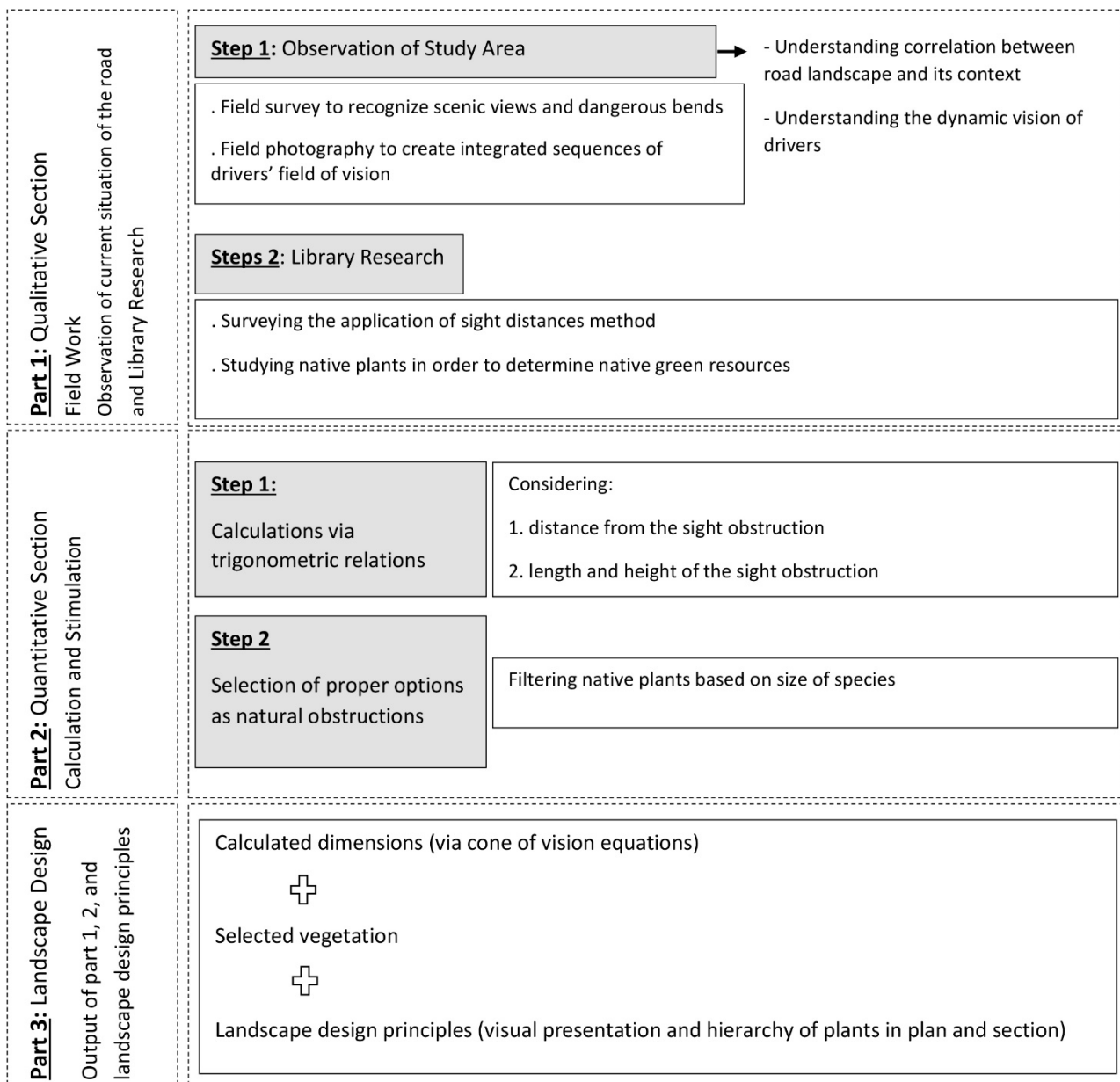


Figure 4. Flowchart.

As shown in Figure 5, the sight triangle is a two-dimensional method. This horizontal restriction is cited in past research as a deficiency that needs to incorporate vertical factors [54]. Additionally, this method does not allow road users to recognize forms, texts, and colors used in road elements. To counteract the issue, an approach is defined, applying cone of vision equations to design areas in which one can see stopped or moving vehicles and natural and built elements.

3.2.2. Cone of Vision in Road Landscape

Cone of vision is a hypothetical cone whose apex implies a driver, and its base marks the movement direction (Figures 6 and 7). Via this cone, in addition to height, three different zones could be established: color, form, and text zones (Appendix A). In this practice, the third dimension is included, by which the distance and dimension of roadside components can be defined in order to emphasize or block them from the drivers' visibility [55].

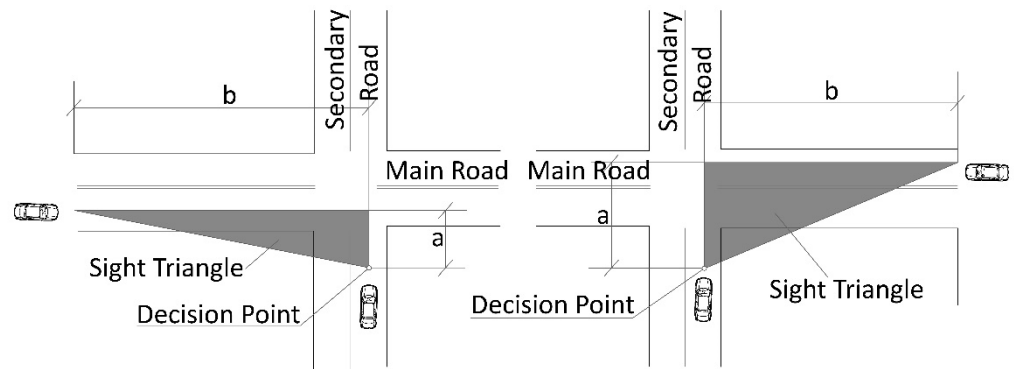


Figure 5. Sight triangle in a junction; (a) the vertical distances (y- and x-axes) of decision points of two drivers moving toward a junction, (b) the horizontal distances (y- and x-axes) of decision points of two drivers moving toward a junction.

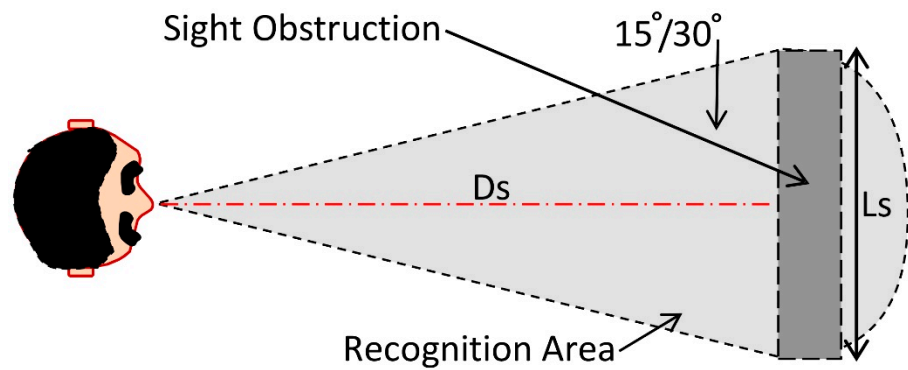


Figure 6. Driver, recognition area, and sight obstruction presentation in plan.

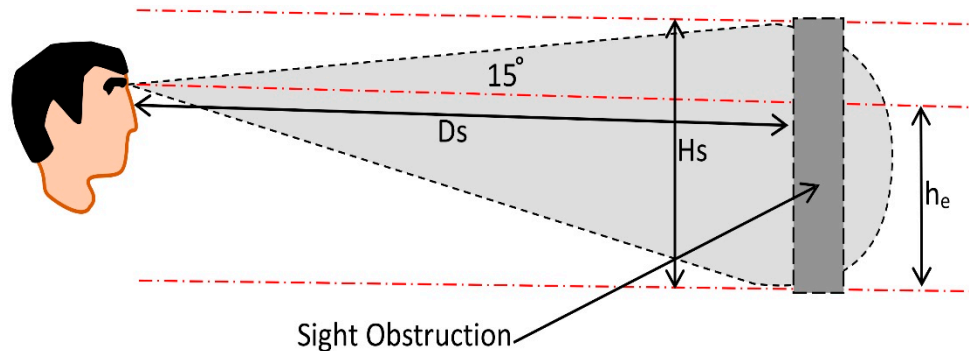


Figure 7. Driver, recognition area, and sight obstruction presentation in sections.

In some dangerous areas such as defiles and bends, should a driver be attracted to natural phenomena in surrounding landscapes, it would end up with distractions and accidents. In these situations, it is advisable to restrict drivers' visibility using built or natural barriers, depending on the budget and other terms and conditions of the project. There are two separate ways to define barrier dimensions:

- Drawing on a map;
- Calculating via trigonometric relations.

In this paper, the second method is used:

1. Sight obstruction dimensions:

$$L_s = 2 \tan 15^\circ D_s \cong 0.5D_s \tag{1}$$

Ls: length of sight obstruction (m) [55]

Ds: distance from obstruction or other objects (signs, vegetation, etc.) (m)

2. Sight obstruction height, according to [55], is as follows:

$$H_s = \tan 15^\circ D_s + h_e \cong 0.3D_s + 1.50 \quad (2)$$

Hs: height of the obstruction

h_e: approximate eye height from the ground

Ds: distance from obstruction or other objects (signs, vegetation, etc.) (m)

4. Results

4.1. Calculations and Simulations

Based on what was mentioned in Section 3.2.2, the calculations would be as follows. With a 20-m distance from the starting point of the bend:

$$L_s = 2 \tan 15^\circ D_s \cong 0.5D_s$$

$$L_s \cong 0.5D_s \cong 10 \text{ m}$$

It is important to point out that the calculated dimension is the minimum, and it can be increased based on project demands and budget. Even though a barrier with 10 m length will cover the main distraction in this study, sight obstruction has been lengthened to the recognition area extent (Figure 8).

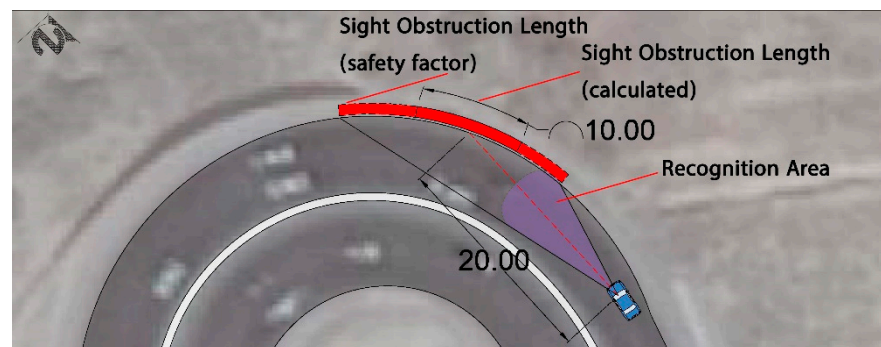


Figure 8. Calculation of sight obstruction length with and without safety factor.

In the following, the height of sight obstruction would be (Figure 9):

$$H_s = \tan 15^\circ D_s + h_e \cong 0.3D_s + 1.50$$

$$H_s \cong 0.3D_s + 1.50 \cong 7.5 \text{ m}$$

Once dimensions have been calculated, designers choose materials ranging from reinforced concrete to vegetation. The most important aspect they should keep in mind is that constructing a wall (20 × 7.5) out of hard materials (Figure 10) could adversely affect road users' visibility. In order to ameliorate the effect of a wall's solid face, a façade could be designed, which can become a distraction itself. From another perspective, road slope, probable landslides, and extreme winds may lead to wall instability. As a restrictive factor, the budget needed for constructing and maintaining a wall would be another setback. As a sustainable solution and so as not to face those predicaments, green resources should perhaps be a substitution (Figure 11).

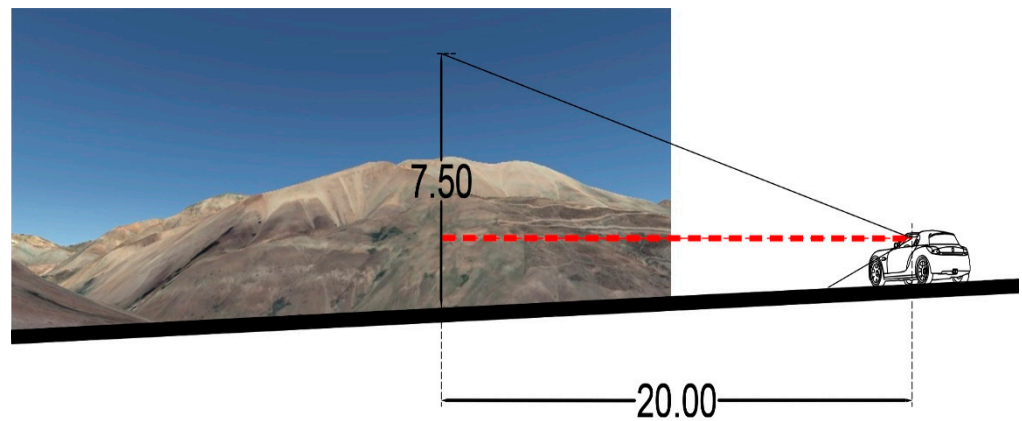


Figure 9. Simulation of sight obstruction height.

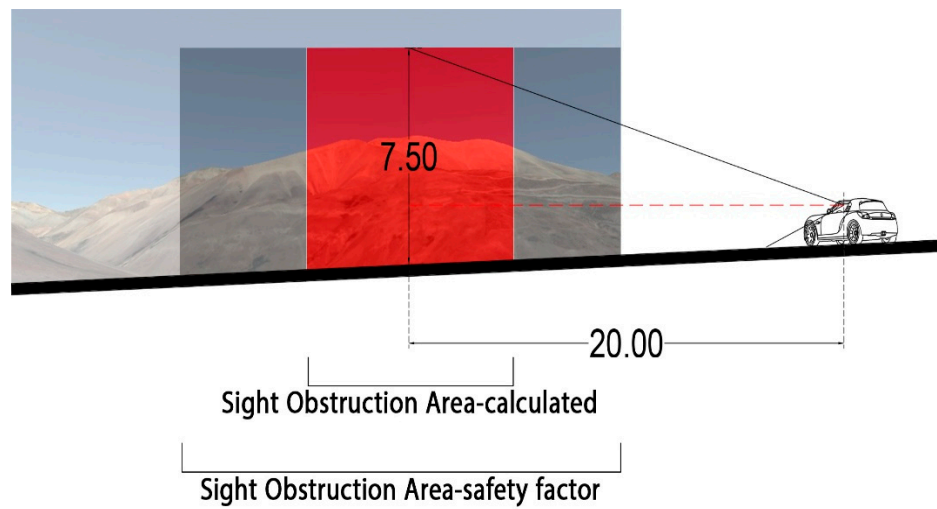


Figure 10. Simulation of the exact area of obstruction.

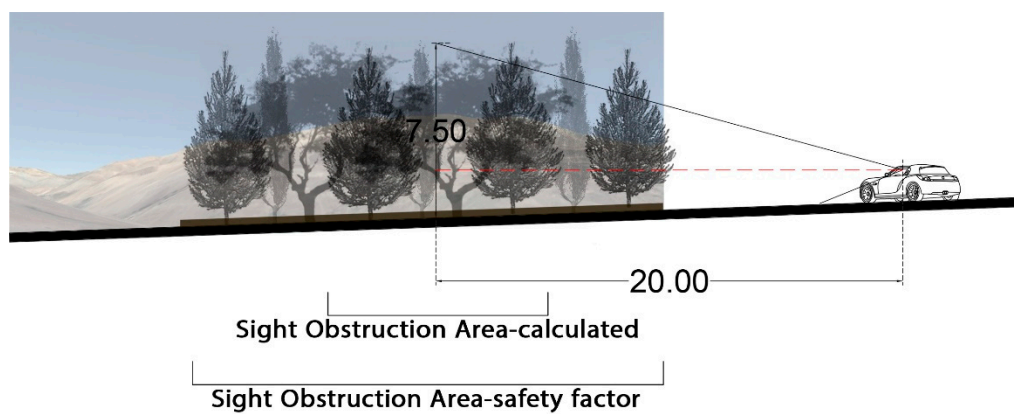


Figure 11. Simulation of vegetation as a sight obstruction with a focus on the 20×7.5 area.

Considering vegetation as a barrier would exert benefits, some of which are (Figure 12a,b):

1. A reduction in costs;
2. Slope stability owing to roots mesh;
3. Doubled safety (guardrail + vegetation).



Figure 12. (a) Dangerous bend with distracting views, (b) sight obstruction simulation.

4.2. Green Resources

Regarding green resources, designers not only pay attention to the main role (sight obstruction) but also consider plants characteristics which make a landscape design “sustainable”. Moreover, a plant community is suggested, especially in roadsides, to alleviate monotony. For instance, trees, shrubs, creepers, cover crops, perennials, grasses, and annual plants are different alternatives [56]. Using a palette of various species with different colors and sizes can positively impact users’ minds [57].

To decide on a sight obstruction in terms of dimensions and material, only the wooded layer has been defined, based on four criteria:

1. Appropriateness;
2. Level of coverage;
3. Wind resistance;
4. Soil stabilization.

4.2.1. Floristic Region: Irano-Turanian

This area is located within the Tethyan Subkingdom of the Holarctic Kingdom, which covers approximately three-fourths of Iran. A distinctive characteristic of this region is low precipitation and long arid seasons. The Irano-Turanian zone is famed for its mountains, plains, plateaus, and abundance of plant species in a wide range of diversity. According to botanists, just below 70% of Iranian plant species can be found in this area [58,59].

The region includes different sections, and the case study belongs to “semi-arid, semi-humid forests”, which encompasses the southern domains of the Alborz Mountains and the northwest to southeast of Zagros heights.

4.2.2. Species

Selecting species were based on Irano-Turanian species, Road Landscape Regulations-Guideline: Road Landscape Vegetation, and the four criteria defined above. Firstly, native species which sustain climatic conditions and integrate with the surrounding landscape should be chosen. A number of non-native species are annually being used in agriculture, horticulture, the pharmaceutical industry, and also as ornamental plants in Iran [60]. Since over-dominance of non-native species may result in local extinctions and a decrease in species richness [61], and invaders can change vegetation diversity and ecosystem functions on a large scale [62], selecting native plants is of high importance. As the design occurs in a mountainous area, it is necessary to select plants enduring harsh winds, improving the resistance of the slope, and controlling soil erosion. Having been discussed in Section 2, the abovementioned features need to be included as essential items of a sustainable landscape design. Another influential factor is the density of leaves needed to cover visual distractions. Based on research and visual impact, it is also known that the proportion of evergreens to deciduous trees should be one in two in green patches [63], and it is a major factor in plant selection. By considering the aforementioned factors, *Pinus mugo*, *Fraxinus rotundifolia*, and *Populus alba* have finally been selected.

Populus alba: Being a large tree (maximum 30 m), it grows in steppes where clay soil can be found [64]. Because of strong roots, it can penetrate to lower levels of the ground, so it is effective in soil stability and resistance against winds.

Fraxinus rotundifolia: The tree grows 18 to 24 m in height with an open crown. It is famous for enduring severe conditions, specifically snowy winds in mountainous areas. It is highly recommended on roadsides because of its resistance to air pollution [58]. Vigorous root growth can be a solution to soil erosion and landslide.

Pinus mugo: The conifer is said to grow to 12 m in height. It is witnessed in mild and cold areas with strong winds as it endures harsh windy conditions [65]. On account of its dense texture, it is used as a hedge or sight obstruction [66].

4.2.3. Plant Composition

Preparation, water requirement appraisal, irrigation system, and maintenance measures are dependent on research conducted by natural resources experts and the description of services enacted by the Forests, Range, and Watershed Management Organization in Iran. In view of the whole spectrum of factors that are beyond the capacity of this paper, only plant spacing coming out of form and external shape is considered.

It is worthwhile mentioning that to create a perpetual sight obstruction, coniferous species would be planted in the first row (Figure 13). Being an imperative item, the height of trees can affect the hierarchy of planting [67], as can be seen in Figure 14.

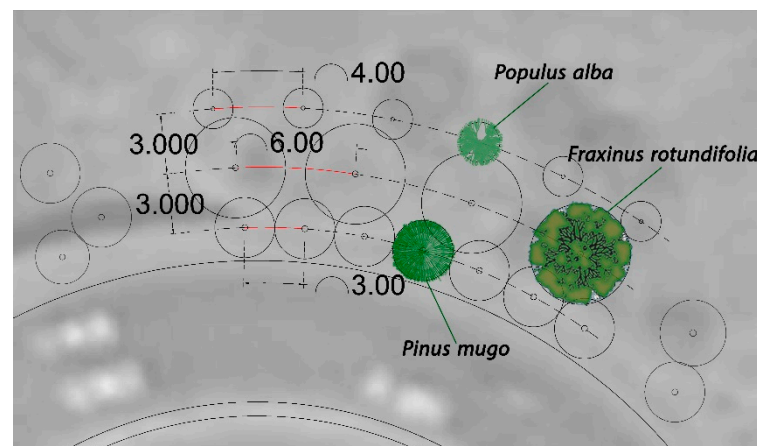


Figure 13. Plant spacing plan based on species and hierarchy.

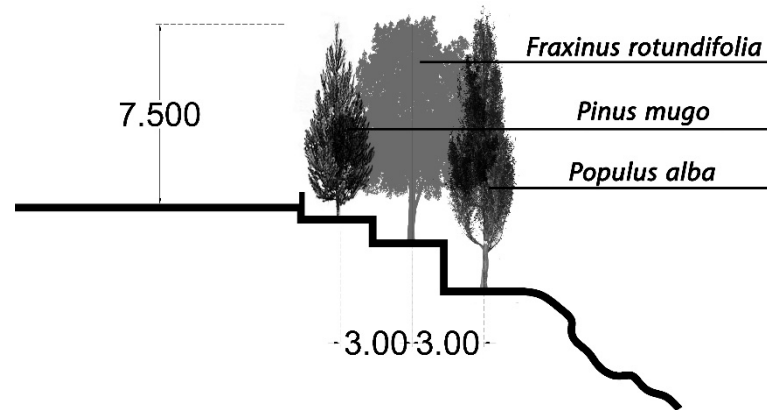


Figure 14. Plant spacing and hierarchy in section.

5. Discussion

Our research depicts that road landscape paves the way for the safe functioning of road infrastructure, improving road environment, creating a sense of place, and integrating the road into the surrounding landscape [68]. Results of this research revealed that landscape design through calculations with a concentration on green resources could potentially boost safety levels by screening disruptive views. It also integrates the road with the character of the surrounding landscape by maintaining the matrix of local vegetation patterns, blending with the local landform and road body.

The main drive of this research can be interpreted by findings of Gue et al. [69], which cite drivers are more likely to pay attention to other moving and stationary targets rather than road conditions in open landscapes such as Lashgarak road's, leading to considerable vehicle trajectory fluctuations. It is claimed that a landscape that is pleasant, beautiful, harmonious, natural, and has elements that match the surrounding environment, causes more car accidents to occur, and the more the road landscape is visually safe and sophisticated, fewer car accidents occur [70]. In the Tehran–Dizin road study, researchers sought a method to change a natural, pleasant, and also hazardous landscape into a safe and locally harmonious one by introducing a green barrier. This can be interpreted by Mok et al [71], stating that there is a correlation between landscape treatments and a reduction in accident rates, which illustrates that landscape along the roadside has a positive effect on drivers' perception and behavior.

Regarding green barriers, results indicate that crown density, root penetration, and height of species are important factors for plant material to meet the safety, economic, and environmental requirements of a landscape design. Based on this, three native species have been chosen, accustomed to local climate and soil conditions so that costs, maintenance, and water consumption are minimized [72], and soil erosion, landslides, and slope instability decrease. The use of native plants can also be beneficial in conserving green resources as it would reestablish the native ecosystem and provide a natural look to roadsides [72]. This is consistent with Lucey and Barton research [31], scrutinizing the evolution of roadside landscape and different approaches towards vegetation management from past eras to to-date strategies. Current strategies for sustainable roadside vegetation embrace an integrated design approach in order to reduce expenditure, minimize maintenance, incorporate regionally appropriate species, and use context-sensitive solutions. These solutions result in the preservation of scenic and environmental resources while maintaining safety along transportation corridors. The paper shows how vegetation serves sustainability by focusing on economic, social, and environmental benefits. Such benefits consist of improved socioeconomic health, cost savings and safety, better water quality, hydraulic conductivity, erosion control, and increased biodiversity [31].

In road landscape studies, different methods consisting of correlation and regression analysis [70], descriptive analysis, statistical tests [68], documentary research, questionnaire survey, Semantic Differential (SD) method—a psychological testing method, using a verbal scale to find out psychological feeling [73], VTI Driving Simulator III [74], driving simulator

and digital model [75], fixed-driving simulator using on-site photos, Google maps street view and a topographical map of the road [76], a photo-based method of assessing visual landscape quality [77], pilot studies [78], and library survey analysis were employed. In this research, the before-and-after landscape design simulation (Figure 12a,b) equips designers with a method to examine the hypothesis that the reliance of road landscape design on cone of vision and trigonometric calculations could positively affect crash rates and the environment. It is recommended that in further research, crash data associated with the landscape of road bends along Lashgarak road would be investigated via bilateral cooperation between landscape architects and traffic safety engineers to identify visual distractions that resulted in serious injuries.

Road landscape planning and management could create unity among various small-scale landscape designs in different spots along the road, benefiting both local and regional scales. In this way, a macro-scale approach shall be suggested, acting as an umbrella under which concepts of road landscape design are subsumed. Tehran–Dizin road includes a number of dangerous bends whose landscape characteristics vary. In this case, a holistic management plan is required to assess landscape features, the level of visibility, and safety in different spots in order to develop comprehensive strategies which would lead to integrated design concepts.

6. Conclusions

This paper recommends a trigonometric-based approach for calculating measures of road landscape elements in order to improve safety. Here, green resources were selected as the main landscape element based on both the suggested method and sustainable landscape design features. The key findings of the study are: (1) The cone of vision could practically be a solution to situations where third dimension plays a key role in addressing safety issues, and applying two-dimensional practices is not adequate. This method can be used to manage drivers' field of view in terms of what should or should not be seen in each view frame. The study emphasizes the importance of mathematical calculations, which should be integrated with the 2D and 3D modeling of a landscape design. Solving not only safety-related matters but aesthetic problems, such a technique could affect people's behavior and perception in terms of roadside beauty, which could be a future topic of research. (2) The green resources can play a fundamental role in upgrading road safety and sustainability of road landscape if they are selected based on road conditions and specific context. 'Planted, non-native species' which can be invasive, have been used for different purposes in landscapes of Iran during recent years. Opting for native species could be a far better substitution as it can (a) help drivers to feel attached to their driving space as those plants integrate with surrounding green areas, (b) enhance the richness of green resources, and (c) contribute to sustainable landscapes on a broad scale.

Author Contributions: Conceptualization M.H., E.C. and A.M.; methodology M.H., E.C. and A.M.; investigation M.H., E.C. and A.M.; formal analysis M.H., E.C. and A.M.; writing M.H., E.C. and A.M. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

Abbreviations

PIARC	Permanent International Association of Road Congresses
HEV	Human–Environment–Vehicle
AASHTO	American Association of State Highway and Transportation Officials
SD	Semantic Differential

Appendix A

Calculating the approximate location of a road sign would be based on distance from the sign, its dimensions, and angle of the cone of vision, as follows:

1. Calculation of Distance, according to [55], is as follows:

$$D_s = \frac{w}{\tan 10^\circ} \cong 6w \tag{A1}$$

W: width of the sign (m)
 D_s: distance from the sign (m)

2. Calculation of the sign height according to [55], is as follows:

$$h = \tan 15^\circ D_s \cong 0.25D_s \tag{A2}$$

h: height of the sign (m)
 D_s: distance from the sign (m)

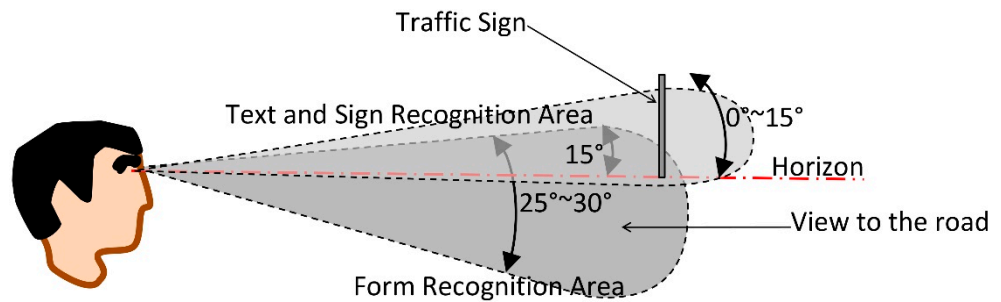


Figure A1. Cone of vision and signs in vertical section.

Minimum distance from text, sign, and color change on the ground would be calculated based on [55]:

$$D = H_e \cdot \tan(90^\circ - \alpha) \tag{A3}$$

D: minimum distance (m)
 H_e: eye height from the ground (m) [approximately 1.5m]
 α: angle of the cone of vision with the horizon (50°, 25°, and 15° for color change, sign, and text respectively)

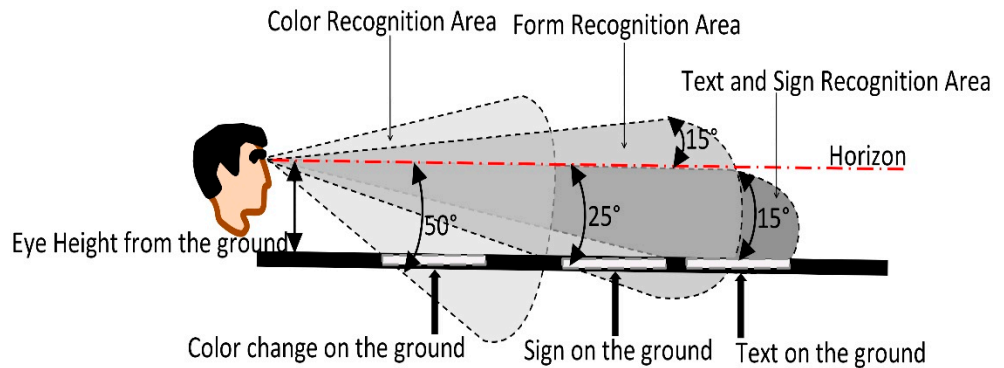


Figure A2. Cone of vision and signs on the ground.

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