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Source / Izvornik: **Sustainability, 2024, 16**

Journal article, Published version
Rad u časopisu, Objavljena verzija rada (izdavačev PDF)

https://doi.org/10.3390/su16031063

sustainability

Review

The Accessible Design of Pedestrian Bridges

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Abstract: Pedestrian bridges are an important component of an active transportation system. As part of digital and green transformation, active travel is recognized as an essential strategy for reducing vehicle fuel consumption and exhaust emissions, but also for improving public health. Pedestrian bridges and other active travel infrastructure must be designed to be accessible to all users. Bridges that do not meet the conditions for comfortable use can force detours that discourage walking and bicycling. Adapting bridges that are not universally accessible requires challenging and expensive construction work. When accessibility issues are considered in the planning and design of new bridges, cost-effective, and often cost-neutral solutions, can be found. Some countries ensure the accessible design of pedestrian bridges through national regulations, but it is important to educate and raise awareness among all bridge designers about the importance of accessible design to achieve sustainable structures. Therefore, this paper provides an overview, comparison and commentary on the most comprehensive current standards, guidelines and manuals for pedestrian bridges that contain information on accessible design. Special attention is given to the design of stairs and ramps as critical elements of bridge accessibility.

Keywords: pedestrian bridges; active transportation; accessibility; inclusive design; ramps; stairs

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Citation: Štimac Grandić, I.; Šćulac, P.; Grandić, D.; Vodopija, I. The Accessible Design of Pedestrian Bridges. *Sustainability* **2024**, *16*, 1063. https://doi.org/10.3390/su16031063

Academic Editor: Elżbieta Macioszek

Received: 25 October 2023
Revised: 12 January 2024
Accepted: 22 January 2024
Published: 26 January 2024

1. Introduction

The call for this Special Issue states that "...the construction industry is one of the fundamental industries worldwide..." and that "...despite good ideas, great efforts, and high investment, many of those projects do not end with success, especially if we are looking at long-term success". This statement applies, in particular, to the design and construction of pedestrian bridges, which play a critical role in the development of an active transportation system, especially in a car-oriented environment. Pedestrian bridges as part of an active transportation infrastructure should be designed and built to ensure an alternative route to relieve traffic congestion, thereby increasing safety and providing pedestrians with safer and more convenient connections to schools, workplaces, parks, health services, etc., in other words, thereby increasing the connectivity of a city [1]. Active travel, such as walking or bicycling (alone or in combination with public transportation), is currently recognized as an essential strategy for reducing vehicle fuel consumption and exhaust emissions and also for improving the public health, such as by reducing heart disease, diabetes, cancer and respiratory diseases [1–3].

Pedestrian bridges and other active travel infrastructure must be designed to be barrier-free, as part of an inclusive society. When we talk about accessibility, we usually think of people with physical disabilities or elderly people. However, this term is actually notably broader. Mobility impairments are also related to a young person who can barely move after a sports accident, to a parent with a baby carriage, or to someone just trying to carry a heavy load. Everyone should be able to cope with everyday life as "normally" as possible and be independent despite their (temporary) disability [4].

Bridges that are not accessible to all users can force detours or disrupt routes entirely, eliminating or discouraging walking and bicycling options [1]. Although pedestrian bridges are primarily viewed as a means to ensure pedestrian safety [5,6], some studies show that they often present accessibility challenges for active commuters [2].

As noted in [7–14], many in-service pedestrian bridges do not meet the conditions for comfortable usage, especially for people with physical disabilities, since the use of steep stairs or ramps is often required.

The adaptation of bridges that do not meet accessibility requirements and/or do not provide sufficient comfort to their users requires construction work, which is challenging and expensive. In some cases, due to both spatial and environmental conditions it is not possible to make the appropriate adaptation [7].

Projects that ensure general accessibility for users may require greater initial financial investment, but in the long-term they ensure the project's quality of use, improve social inclusion and contribute to sustainable urban change. When accessibility is taken into account in planning cost-effective solutions, often even cost-neutral solutions can be found [4].

Ideally, a pedestrian and/or cyclist bridge will be the final result of coordinated strategic route planning. Simulation models for evaluating and optimizing the design of transit facilities in order to ensure sustainability and accessibility can be found in [15]. To achieve optimum accessibility, the location of the bridge should not detract from an existing footpath/cycle path. If this is unavoidable, the detour may need to start well away from the bridge to achieve the desired results [5]. The design of pedestrian bridges must not only meet the objective criteria of limit states, but also the subjective criteria of personal safety (like unpleasant vibrations, lightning at night, etc.) and accessibility for bridge users. Each bridge should undergo a comprehensive options analysis to determine the most appropriate location and configuration of spans, structure type, material and access options [16].

Some countries ensure the accessible design of pedestrian bridges through their national regulations [5,6,16–21], but it is important to educate and raise awareness among all bridge designers about the importance of accessible design for all users.

Studies conducted in some low- and middle-income countries in South America, Africa and Asia show that the use of pedestrian bridges is low (in many cases, bridge use in lieu of jaywalking ranges from 20% to 50%). Among other reasons, detours, mobility challenges and personal safety concerns are recognized as predictors for avoiding pedestrian bridges [1].

Although many bridge designers are convinced that the combination of stairs and elevators or platform lifts will provide universal accessibility (which is what some regulations on accessibility [22] prescribe), this is rather doubtful. Keil [6] states, "Elevators in public spaces must be very robust (e.g., to withstand vandalism)...", but vandalism is often the reason elevators are out of service, sometimes even for several months [23]. Hence, some of the current bridge design standards and guidelines do not allow the construction of bridge approaches without ramps [17–19], while some allow stairs [5] or a combination of stairs and elevators [6] only as an exception. The U.S. Agency of Architectural and Transportation Barriers Compliance Board in [24] has eliminated platform lifts as an option to achieve the accessibility of overpass structures in new construction due to their limited use, the difficulty for users with disabilities to independently operate the lifts and frequent breakdowns in outdoor environments.

To raise awareness of the key issues in inclusive design, this paper provides a literature synthesis of some of the current standards, manuals and guidelines for the accessible design of pedestrian bridges, focusing on stairs and ramps as the critical elements of bridge accessibility.

2. Guidelines, Manuals and Standards on the Accessible Design of Pedestrian Bridges

One of the first comprehensive guides for the design of pedestrian bridges, *fib* Bulletin 32: Guidelines for design of footbridges [25], was published in 2005. This document provides guidelines for the design of pedestrian bridges, as well as bridges for bicyclists and equestrian trails. The guide is intended to be a source of information for all design issues related to pedestrian bridges: it contains data from international standards at the time of publication, recommendations, authors' experiences and built examples with comparisons and observations. However, no special attention is given to general accessibility, although some aspects of accessible design are included in the conceptual design and geometrical conditions of the bridges. For example, it is stated that although "for wheelchair users grades of more than 6% are difficult to handle. . .bridge inclination and length shall be considered together. A slope of 8% over a length of 5 m will be easier for wheelchair users to overcome than a slope of 5% over a length of 200 m". Therefore, the authors [25] suggest that the allowable slope should not be determined by the maximum slope at one point in the structure, but should be instead derived from the conditions of potential energy that a person with a disability must overcome.

Over the past two decades, there has been a significant increase in awareness of the need for universally accessible design in buildings, public spaces, public transportation, etc. Most of the current standards, manuals and guidelines for pedestrian bridge design in developed countries include aspects of accessible design in terms of their spatial design. Next, the most comprehensive standards, manuals and guidelines on the inclusive spatial design of pedestrian bridges are presented. The selection of standards, manuals and guidelines (Table 1) is based on the following criteria:

(a) The standard/manual/guideline defines its criteria for accessibility, such as the usable widths and heights of the bridge and approaches to the bridge, design of ramps, design of stairs and design of other elements that ensure accessibility (railings, handrails. . .),
(b) The standard/manual/guideline is currently valid,
(c) The standard/manual/guideline is written in English so that it is easily accessible and available to engineers.

Table 1. Selection of standards, manuals and guidelines.

Standard/Manual/Guideline	Publisher	Year
CD 353 Design criteria for footbridges	Highways England, UK	2020
Options for Designers of Pedestrian and Cyclist Bridges to achieve value-for-money	Department of Transport and Main Roads State of Queensland, New Zealand	2018
Brief Dutch Design Manual for Bicycle and Pedestrian Bridges	ivpDelft, The Netherlands	2014
CDOT Bridge Design Manual	Colorado Department of Transportation, USA	2023
Structures Design Manual for Highways and Railways	Highways Department of the Hong Kong Special Administrative Region Government, Hong Kong	2013 (last revision 2023)

2.1. CD 353 Design Criteria for Footbridges

2.1.1. General

This document [5] was published by Highways England in 2020 and applies to the design of pedestrian bridges in the United Kingdom. In addition to general principles, layout and appearance, and design standards, an entire chapter is devoted to dimensional standards (including clearances to the roadway under the bridge, minimum width, headroom clearance on the bridge, the landings and horizontal alignment on ramps, spiral and curved ramps and stairs). This document also includes chapters on parapets, enclosed pedestrian bridges, drainage, walkway surfaces and lighting.

The general accessibility requirements for bridges that can be used by pedestrians as well as bicyclists and equestrians are as follows [5]:

- The location and arrangement of the bridge should be chosen to take advantage of both natural and man-made slopes and local topography; abutments should be at or near the ground level of the surrounding area whenever possible to accommodate access ramps and steps, or to reduce the need for them.

- If the bridge is a part of an existing rural footpath, bypass or secondary trail, any diversion should be designed to minimize the overall length of the trail and maintain the existing desire line.
- The choice of slopes and landings (rest areas), as well as the turning radius and space for maneuvering, should meet the needs of all potential users, including people with mobility problems, bicyclists and equestrians.
- Access ramps and stairs should be simple, short and as direct as possible; they should follow the desired main direction of traffic and avoid long detours or unnecessary slopes.
- If the ramps provide the most direct route to the bridge's span structure, stairs may be omitted.
- Access with stairs only should be allowed only in exceptional cases and with the consent of the local population and disability groups.
- An appropriate width and clear height/headroom clearance on the bridge have to be applied to meet the needs of all potential users (see Figure 1).

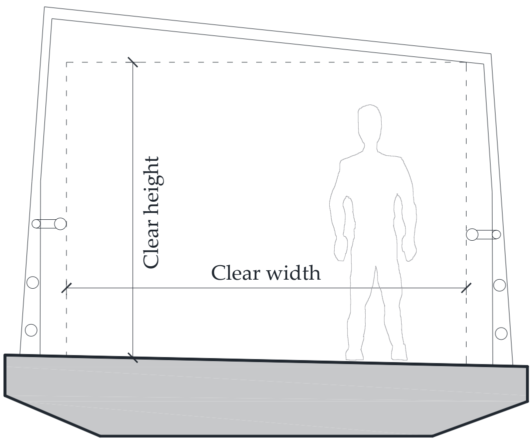

Figure 1. Definition of clear width and clear height of a bridge.

The minimum clear width of walkways, ramps and stairs is given for both pedestrian-only use and combined pedestrian and bicycle use, as well as combined pedestrian and equestrian use. For pedestrian-only use, the minimum clear width is 2 m or the greater dimension based on projected peak pedestrian traffic and the slope (0.3 m per 20 persons per minute on flat parts and slopes of 5% and shallower; 0.3 m per 14 persons per minute on steps, or where the slope is 6.67% or steeper; for slopes between 5% and 6.67%, linear interpolation should be used). For unsegregated combined use, the minimum width is 3.5 m. The most detailed dimensions of the clear width of pedestrian and bicycle paths are given for segregated pedestrian and bicycle use (depending on the method of segregation). In case of segregated combined use, the pedestrian walkway minimum widths are defined as 1.5 and 2 m, and cycle path minimum widths are 2.5, 2.7 and 3 m, while the minimum total clear widths should be 4, 4.7 and 5 m.

The minimum clear height should be as follows: pedestrian only, 2.3 m; pedestrian and bicyclist, 2.4 m; dismounted equestrians, 2.7 m; and mounted equestrians, 3.7 m.

In general, the maximum slope on the bridge and access ramps should not exceed 5% (1:20). In some cases (an excessively long detour, unacceptable environmental impact, etc.), a slope of up to 8.3% (1:12) may be applied. Steeper slopes are not permitted. The maximum cross slope of the bridge/ramp/landing is not specified.

Handrails should be provided on both sides of stairs and on walkways on bridge decks and ramps when the slope exceeds 5%. Additional handrails in the middle should be provided when the width of the walkway exceeds 3 m.

2.1.2. Ramps

Ramps can be straight as well as spiral or curved. The width of the ramp should be equal to the width of the pedestrian/bicycle/combination path on the bridge. The maximum slope of the ramp is specified in the previous subsection. The minimum inside radius of curved and spiral ramps should be 5.5 m (a larger-curve radius may be required for bicyclists and/or equestrians, but the value is not specified). The effective slope and governing dimensions for spiral and curved ramps are measured 90 cm from the edge of the walking surface on the inside of the curve. Ramps with a slope of up to 4.5% may be constructed without intermediate horizontal landings. For slopes greater than 4.5%, intermediate horizontal landings should be constructed as follows (see Figure 2):

- for slopes between 4.5% and 5%, at equal vertical intervals (h) not exceeding 2.5 m in height,
- for slopes of more than 5%, at intervals (h) not exceeding 0.65 m in height.

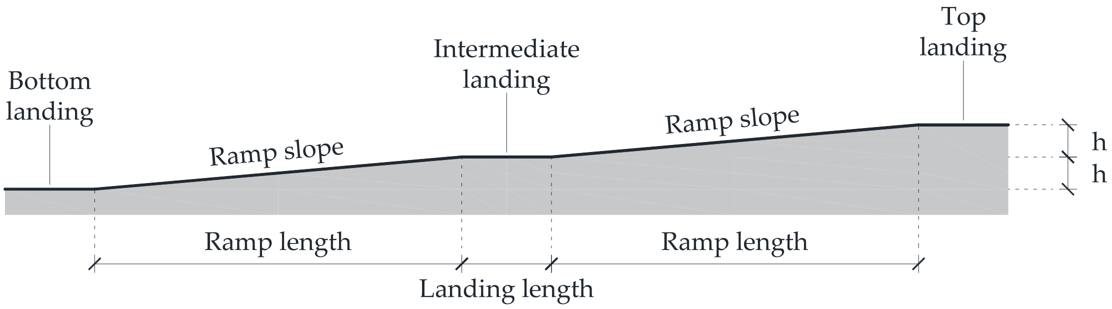

Figure 2. An example of a ramp with an intermediate landing.

The minimum length of a landing is 2 m, while the width should be the same as the ramp width.

Straight ramps with slopes greater than 5% should change their horizontal alignment at intervals equal to a vertical rise of 3.5 m by either a change in direction of at least 30° or an offset in horizontal alignment of at least the width of the walkway. Exceptions can be made if no arrangement other than straight successive sloped ramps is possible at the site, or if such an arrangement would encourage pedestrians more strongly to use the pedestrian bridge by shortening the walking distance or improving the desire line.

2.1.3. Stairs

Public stairways may have no more than 13 risers in a single flight; the riser and going have to be uniform in a flight of stairs (with the riser not exceeding 15 cm and going not less than 30 cm). The landing length should be at least the width of the stairway or 2 m, whichever is greater, measured along the centerline of the stairway (Figure 3). Risers may be solid or perforated, but not completely open. If risers are perforated, they should meet the following conditions: the maximum principal dimension of the perforation is 5 cm; the ratio between the open area and the total area of the riser is not greater than 0.4.

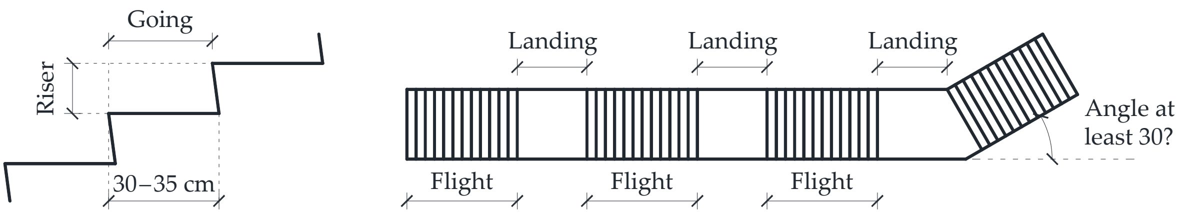

Figure 3. Public stairs adopted from CD 353 ((**left**): cross section; (**right**): in-plane arrangement) [5].

A maximum of three consecutive flights may be arranged in a line; adjacent flights have to change direction at an angle of at least 30°, as can be seen in Figure 3.

2.2. Options for Designers of Pedestrian and Cyclist Bridges to Achieve Value-for-Money

2.2.1. General

The main design reference for all bridges in Australia and New Zealand is AS (/NZS) 5100.1:2017 [26]. The manual [16], which defines the design criteria for bridges and other structures, published in February 2021 in compliance with Standard [26], refers to the application of the guideline Options for Designers of Pedestrian and Cyclist Bridges to achieve value-for-money (ODPCB) [17] in the design of pedestrian bridges. ODPCB, issued in 2018, provides a summary of design considerations that address the development, construction and routine maintenance costs of pedestrian and cyclist bridges based on Standard [26], and includes requirements for pedestrian bridges that are not included in [26].

Although the main objectives of ODPCB [17] are to provide an overview of appropriate design references, review life-cycle cost factors that affect value-for-money and identify opportunities for cost savings and potential innovations, part of the guide is focused on the suitable user envelope and ensuring access and mobility.

For pedestrians, the minimum clear width between handrails is 1.8 m, while a minimum width of 2 m is allowed on one-way bicycle paths with low traffic volumes, although such bridges are rare. For dual use (bicyclists and pedestrians in both directions) and separated bike lanes the minimum width is 3 m. Minimum vertical clearances above the walking/cycling surface are as follows: for cyclists and shared use, 2.7 m; for pedestrians, 2.4 m.

For pedestrian-only bridge structures or shared-use bridge structures, access for users with reduced mobility shall be provided by walkways and ramps. The approaches to the bridge using walkways and ramps are identified as a potential cost of the bridge, hence careful design (including the selection of the most appropriate grade, minimization of the bridge superstructure depth and careful evaluation of the required bridge clearance), can reduce the length of the approach facilities. Stairs can be provided as an additional means of access, but they always increase the total cost of a bridge.

2.2.2. Walkways and Ramps

In ODPCB [17], a distinction is made between walkways and ramps based on their slope. For slopes between 3% and 5%, access is defined as a walkway; for slopes greater than 5%, access is defined as a ramp.

According to ODPCB [17], the slope of a ramp for bicyclists' use only should comply with Austroads Part 6A [27], while for pedestrians' use only, including people with disabilities, the slope according to the standard AS 1428 [28,29] should be applied.

The recommended slopes for pedestrians [17] are up to 3%, in which case no landings are required. If the slope exceeds 3%, landings should be provided. The landing interval depends on the slope and the user comfort, as presented in Table 2. The interval for intermediate slopes is obtained by linear interpolation. Enhanced requirements for landing intervals may be applied to provide a greater level of accessibility [29]. Slopes greater than 7.1% are not allowed for pedestrian and combined use.

Table 2. Landing intervals.

Slope	Landing Interval *
3%	25 m
5%	14 m
7.1%	9 m/6 m **

* Where a curb and a handrail are provided these values can be increased by 30%. ** general [28]/enhanced [29].

Cross slopes on a walkway should be as shallow as possible to provide an adequately drained surface. Excessive cross slope causes problems for some people; according to [27] the cross slope should not exceed 2.5%.

2.2.3. Stairs

For public stairs, the values for the going (G), riser (R), and sum (2R + G) are required to comply with the values presented in Table 3. In addition, the value of the maximum slope is set at 62.5%.

Table 3. Stairway configuration (in cm) [17].

Riser (R)		**Going (G)**		**(2R + G)**	
Max	Min	Max	Min	Max	Min
19	11.5	35.5	25	70	55

If the bridge provides access to schools, design standards for school buildings require that the going should not be less than 30 cm and the risers should not exceed 17.5 cm (preferably 15 cm for elementary school students). For students, each flight should have at least two, and no more than eight, risers.

The risers should not be open; where this is difficult to achieve an opening of up to 17.5 cm in diameter is permissible.

2.3. Brief Dutch Design Manual for Bicycle and Pedestrian Bridges

2.3.1. General

The Brief Dutch Design Manual for Bicycle and Pedestrian Bridges (BDDM) [21] was published in 2014 by ipv Delft, a design and engineering office specializing in infrastructure, large-scale bicycle, road and pedestrian bridges and bicycle infrastructure-related research. This manual was prepared at the request of the Dutch technology platform for transport, infrastructure and public spaces, CROW [30]. The BDDM focuses on the basics of bridge design including aesthetics and accessible design. It contains considerations that have to be made before the actual design, and gives an insight into the Dutch regulations on loads and impact forces. Also, several projects are presented and discussed to illustrate its theoretical principles.

According to the BDDM [21], the key to successful design for pedestrians is accessibility. Therefore, the bridge should preferably be free of obstacles, should have a gentle ramp slope (if any) and should provide a direct route from the adjacent sidewalk or walkway to the bridge without giving the impression of a detour. Since bicyclists travel at much higher speeds, some additional requirements for bicycle bridges should be considered; they should provide a clear view of the road, take into account the fact that bicyclists tend to swerve and lean uphill or on curves and therefore need more horizontal space, and have a smooth transition between flat and sloped sections.

In order to ensure the safe use of bridges for pedestrians, the minimum width of 1.5 m (between railings) should be respected (it is recommended that 1.8 m should be accepted as the minimum width if possible). The minimum width for bicycle lanes in one direction is 1.4 m, while for bicycle lanes in both directions it is 2.4 m. The required additional width for the horizontal clearance of bicycles during leaning and swerving, as well as for various bridge protection devices (railings, traffic signs, etc.), is indicated. No vertical clearances (headroom) are specified. For height differences of more than 0.21 m, a ramp or several steps should be used.

When designing a bridge element in a curve, the horizontal radius should ideally be between 10 m and 20 m. If space is limited, the radius of the curve should be at least 5 m.

Except for bridges with less than a 1 m drop, bicycle and pedestrian bridges need to have railings for safety reasons.

2.3.2. Ramps

The minimum ramp width for pedestrians is 1.1 m. The maximum height difference that a single ramp can overcome is 1 m, while for people with disabilities this is reduced to 0.5 m. A greater height difference should be overcome by several ramps connected by flat landings.

The average slope of the ramp plays a more important role than its length. The difficulty (Z) of the ramp can be calculated as the square of the average slope of the ramp multiplied by its length, or as the square of the height difference divided by its length:

$$Z = (h/L)^2 \times L = h^2/L, \tag{1}$$

where h is the height difference, L is the ramp length and Z is the difficulty.

The ideal ramp difficulty (for middle-aged cyclists in normal conditions and average wind) is 0.075, with a maximum slope of 7.5% and a minimum slope of 1.75%. The lower bound for difficulty is 0.0333, with a maximum slope of 6.67% and a minimum slope of 1.25%. Slopes less than 1.25% are not considered because they are so-called false flats. The upper bound for difficulty is 0.2, with a maximum slope of 10% (Figure 4).

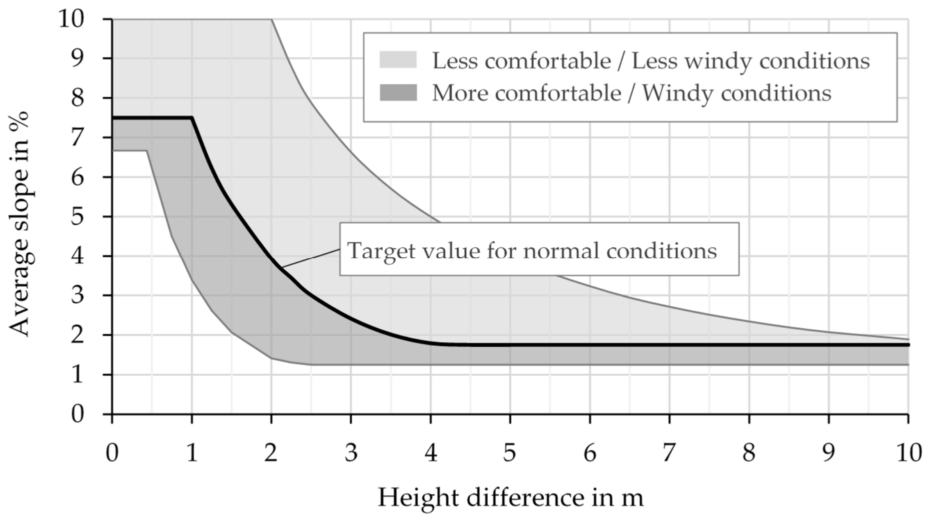

Figure 4. Slope bandwidth in relation to different conditions and height differences, adopted from [21].

2.3.3. Stairs

The greatest height difference that can be overcome with a flight of stairs is 4 m. For larger height differences, landings should be provided with the smallest dimensions of 80 by 80 cm and, if possible, 120 by 120 cm, as shown in Figure 5. No additional design parameters for stairs are given.

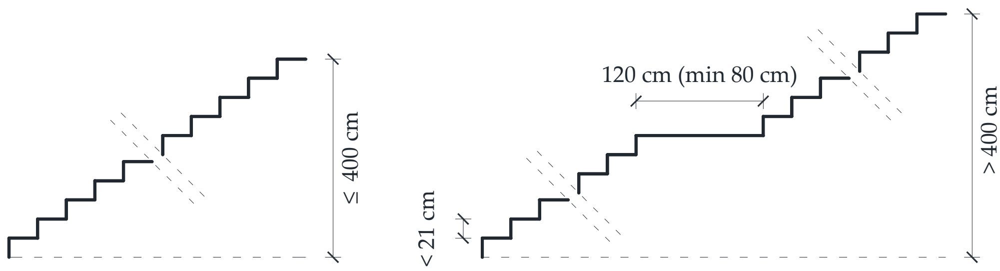

Figure 5. Arrangement of stair flights in relation to height differences, based on BDDM [21].

2.4. CDOT Bridge Design Manual

2.4.1. General

The Bridge Design Manual (BDM) [18] was published in February 2023 by the Colorado Department of Transportation. The BDM provides the policies and procedures currently in effect for the design, rehabilitation and repair of bridges and other highway structures that are within the CDOT's right-of-way (ROW) and for projects that use federal or state funds.

This BDM is also recommended as the best practice for any Colorado project that does not contain federal or state funds [18]. The BDM includes a chapter dedicated to the design and performance requirements for typical pedestrian bridges intended to carry pedestrians, bicyclists, equestrian riders and light maintenance vehicles.

Design parameters for ensuring accessibility, such as geometry and clearances, are generally based on the ADA Standard [20] and the CDOT Roadway Design Guide [31].

The ADA standard and CDOT Roadway Design Guide (RDG) define the minimum width for an accessible route/walkway as 152.5 cm (two people passing in wheelchairs). If the width is less than 152.5 cm, passing areas of a minimum of 152.5 by 152.5 cm have to be provided at maximum horizontal intervals of 61 m [20,31]. In that case, the width of the walking surfaces should be at least 122 cm [31].

A clear height of a minimum 203 cm between the walking surface and overhead obstacles has to be assured [20,31], while for bicyclists or shared use a height of 254 cm is recommended.

The longitudinal slope of walking surfaces should not be steeper than 5% [20,31] while the cross slope is limited to maximum 2% [20,31]. A walkway with longitudinal slope steeper than 5% should be designed as a ramp. The cross slope of a shared-use walking surface should be designed to allow rain and snowmelt to run off the walking surface (the minimum cross slope is 1%).

The BDM specifies that pedestrian access to overpasses may be provided with both ramps and stairs; stair-only access is not allowed.

Any vertical discontinuity (change in level) greater than 6.4 mm and smaller than 13 mm should be beveled with a slope not steeper than 1:2, as seen in Figure 6.

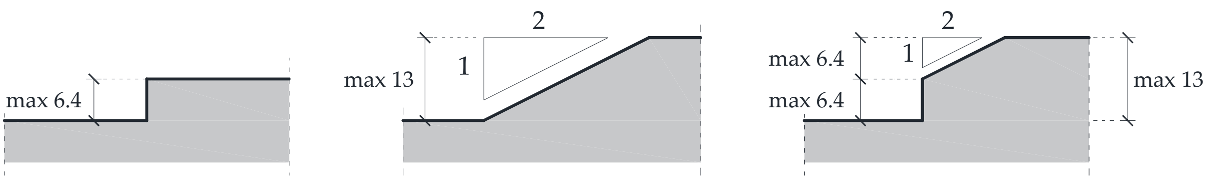

Figure 6. Allowable vertical and beveled change in level on walkways in mm, adopted from [20,31].

All stairs should have handrails designed according to [20]. Handrails should be provided on both sides of stairs and ramps. Handrails are not required on walking surfaces with longitudinal slopes less than 5% [20] or ramps with a rise up to 15 cm [31].

2.4.2. Ramps

The minimum clear width of ramps and landings [18] is defined as the full width of the bridge or 152.5 cm, whichever is greater. The minimum landing length is 152.5 cm. Ramps should have landings at the top and at the bottom of each ramp run (Table 4) and whenever the direction of the ramp changes. The design of ramps for wheelchair users is described in detail in the ADA [20].

Table 4. Maximum slopes and ramp heights for new bridges [31].

Slope	Maximum Height	Maximum Horizontal Length
$5\% < s \leq 6.25\%$	76 cm	1220 cm
$6.25\% < s \leq 8.3\%$	76 cm	915 cm

Ramp slopes on pedestrian bridges should be in accordance with [20,31]: a maximum longitudinal slope of 8.3% and maximum cross slope of 2%. Slopes of less than 5% are not considered ramps but walkways.

However, ramps with a longitudinal slope bigger than 8.3% are permissible for existing sites, buildings and facilities due to space limitations [20], as presented in Table 5.

Table 5. Maximum slopes and ramp heights for existing structures [20].

Slope	Maximum Ramp Height
8.3% < s ≤ 10%	15 cm
10% < s ≤ 12.5%	7.5 cm

2.4.3. Stairs

All steps in a flight should have uniform riser heights and uniform going depths. Risers should be a minimum of 10 cm high and a maximum of 18 cm high. Goings should be a minimum of 28 cm deep. Goings are permitted to have a slope not steeper than 2%. Open risers are not permitted. When designing stairs, Figure 7 should be observed.

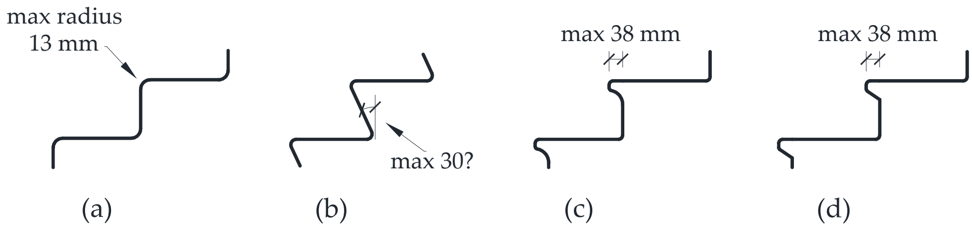

Figure 7. Stair design: (**a**) radius of stair edge (typical for all profiles), (**b**) angled riser, (**c**) curved nosing, and (**d**) beveled nosing (adopted from [20]).

2.5. Structures Design Manual for Highways and Railways

2.5.1. General

The Structures Design Manual for Highways and Railways (SDM) [32] was published in its 4th edition in 2013 by the Highways Department of the Hong Kong Special Administrative Region Government. Four revisions of the SDM have been made, in 2018, 2020, 2021 and January 2023. In the 2013 edition, the manual was revised to reflect the transition from British design standards to Eurocodes. The design of pedestrian bridges is included in this manual; moreover, the provision of access for people with disabilities is a mandatory requirement.

The SDM [32] states that a pedestrian bridge has the potential to be efficient only if it accommodates the basic directional movements of potential users; a study of existing and future pedestrian movements should be made before selecting the best layout of a pedestrian bridge. If ramps or stairs are used, access to the bridge should be as short and direct as possible to avoid long detours.

The minimum clear width of the walkway area on pedestrian bridges, elevated walkways and associated ramps and stairs should be 2 m.

Headroom on enclosed bridges should meet the requirements of Table 6.

Table 6. Headroom on enclosed bridges, according to [32].

Users	New Construction Length		Maintained Construction Length	
	<23 m	**≥23 m**	**<23 m**	**≥23 m**
Pedestrians	2.3 m	2.6 m	2.3 m	2.5 m
Bicyclists	2.5 m	2.7 m	2.5 m	2.5 m

Handrails should be provided on both sides of all ramps and stairs. For stairs 4 m wide or more, central handrails should be considered.

Footbridge decks should be provided with a longitudinal slope of not less than 0.67%.

Any change in direction should be curved to the minimum radius of 4.6 m.

2.5.2. Ramps

The minimum clear width of a ramp is 2 m.

Pedestrian ramps should have a slope not exceeding 8.3%. A steeper slope of up to 10% is permitted where space is limited, with the approval of the Assistant Commissioner for Transport, Transport Department. The slope of spiral ramps should not exceed 10% (measured at the centerline). Ramps should be provided with landings at vertical intervals not exceeding 3.5 m. The slope of bicycle ramps should not be steeper than 4% (in exceptional cases it may be increased to 8% if space is limited).

Landings connecting successive ramps should be as wide as the connecting ramps and 2 m long (1.5 m if space is limited). The minimum radius of curved parts is 4.6 m.

2.5.3. Stairs

The number of risers in a flight should not exceed 12 (16 if space is limited). Successive flights should be connected with landings as wide as the connecting flights and between 1.5 and 1.8 m long (1 m if space is limited).

Stairs should have solid risers (R) of a maximum of 15 cm high (16.5 cm if space is limited and if an alternative route for people with disabilities is available). Goings (G) should be a minimum of 28 cm wide (25 cm if space is limited). The sum 2R + G should be between 58 cm and 60 cm. Also, the product RxG should be between 420 cm and 450 cm.

3. Discussion

The following section summarizes, compares and comments on the accessibility design parameters described in the previous section.

The location of a bridge should be chosen in such a way that its connection to the existing footpath/cycle path is guaranteed without a detour. If a detour cannot be avoided, the detour may have to start far away from the bridge.

To ensure bridge accessibility, the walkway on a bridge deck preferably should not be elevated with regard to the approaching walkway or path, and should be as flat as possible. This is a rather rare situation because pedestrian bridges are often built over other transportation infrastructure (like roads, highways, waterways, etc.), and the vertical difference between the walkway levels is unavoidable. The vertical difference can be reduced by choosing shallow bridge deck structures such as plates, stressed ribbons, suspension structures or cable-stayed structures. The height difference can be overcome by sloped or curved walkways (including the walkway on the bridge deck), ramps and stairs. In some cases, elevators and elevator ramps can be installed as additional accessibility measures.

Special attention should be paid to the design of a bridge approach with ramps and stairs. Ramps and stairs have to be simple, short and as direct as possible, thereby avoiding long detours or unnecessary slopes. It is recommended that ramps are used in combination with stairs; elevators and lift ramps in combination with stairs are not reliable for general accessibility in outdoor environments [5,6,17–19,23,24]. If the bridge is used only by pedestrians, ramps can be omitted due to space limitations, only with the consent of local residents and disabled groups [5]. By all means, bridges should not be built without ramps if they are intended for cyclists or shared use by pedestrians and cyclists.

Both sides of ramps and stairs should be equipped with handrails. Handrails on ramps can be omitted only when the rise is smaller than 15 cm [31] or when the ramp slope is up to 5% [5,20].

The slope of the walking surfaces on the bridge and bridge approaches should be limited to meet the requirements of comfortable traffic for all users, but also to provide an adequately drained surface. Excessive cross slope can cause problems for some people. Consequently, the cross slope limit is set between 2% [4,20,31] and 2.5% [27]. A minimum cross slope of 1% [20,31] and minimum longitudinal slope of 0.67% [32] will ensure adequate drainage.

Recommended longitudinal slopes for comfortable pedestrian use are up to 3% [17], while for cyclists they are up to 4% [32]. A slope of up to 6% meets the needs of persons with reduced mobility and wheelchair users [6,25]. In general, the maximum slope on bridges and access ramps should not exceed 5% [5,20,31]. Slopes steeper than 5% may be applied in the case of limited space or special conditions.

The maximum slopes of ramps, which should not be exceeded for new bridges, are as follows: 7.1% [17], 8.3% [5,31] and 10% [21,32]. For existing bridges, slopes may be up to 12.5% [20].

Ramps should have landings at the top and at the bottom of each ramp and whenever the direction of the ramp changes. As mentioned earlier, the allowable slope should not be fixed at one point on the structure: the relationship between the steepness of the ramp and the ramp length is an important parameter for the comfort of the ramp [21]. Intermediate landings reduce the average slope of the ramp and are therefore recommended for steeper ramp slopes.

No intermediate landings are required for shallow sloped ramps (for example up to 3% [17] or up to 4.5% [5]). For steeper slopes, horizontal landings should be constructed at prescribed distances to reduce the overall slope, as presented in Table 7. For example, in the case of two ramps with a slope of 8.3%, connecting them by a 2 m long landing at a vertical distance of 0.7 m creates a reduction in the overall slope to 7.45%.

Table 7. Landings on ramps.

Reference	Slope	Vertical Distance	Horizontal Distance	Landing Length
CD 353 [5]	4.5% to 5% 5% to 8.3%	≤2 m ≤0.65 m	- -	≥2 m
ODPCB [17] *	3% 5% 7.1%	0.75 m 0.70 m 0.64 m/0.43 m **	25 m 14 m 9 m/6 m **	-
BDDM [21]	1.25 to 10%	≤0.5 m	-	-
RDG [31]	5% to 6.25% 6.25% to 8.3%	≤0.76 m ≤0.76 m	≤12.2 m ≤9.15 m	1.5 m
ADA [20] ***	8.3% to 10% 10% to 12.5%	≤0.15 m ≤0.075 m	- -	-
SDM [32]	up to 10%	≤3.5 m		≥2 m (1.5 m)

*, for intermediate slopes linear interpolation is used; **, general [28]/enhanced [29]; ***, for existing bridges.

As displayed in Table 7, the recommendation for landing intervals on ramps prescribed by the SDM [32] differs substantially from all other recommendations, and we do not recommend using it. The strictest is the BDDM [21], with a vertical interval of not more than 0.5 m for the use of all slopes by people with disabilities. For slopes between 5% and 8.3% the values for vertical intervals are quite similar (between 0.64 m and 0.76 m) [5,17,18,20,21,31,32]. The enhanced requirements [29] are intended as a reference for authorities and other users who wish to ensure better accessibility than with the general requirements [28].

We recommend that slopes steeper than 8.3% are by no means used for new bridge structures. The reasons are as follows: a slope of 8.3% is the steepest slope that a person in a wheelchair can overcome without assistance [32], while slopes between 7.5% and 10% are considered the upper limit of ramp difficulty [21].

Additional recommendations for ramps are that straight ramps with slopes greater than 5% should change their horizontal alignment at intervals corresponding to a vertical difference of 3.5 m [5], while any curved change of direction should have a radius of at least 4.6 m [32].

Very little information is available about the design of curved or spiral ramps: the preferred radius of spiral or curved ramps is 10–20 m [21] while the minimum radius is set to 5 m [21] or 5.5 m [5]. The maximum slope of a spiral ramp, measured at centerline, is 10% [32].

The vertical distance between bridge approaches and the bridge deck can be covered by a single flight or more that one flight of stairs. The height that can be overcome by a single flight of stairs is specified as the maximum height or is determined by the maximum number of risers in the flight. For greater vertical differences, successive flights, connected by landings, should be used. The manual [21] states that vertical distances of up to 4 m can be covered in a single flight, but we do not recommend using such long flights if general accessibility is to be achieved. We suggest using the recommendations given in CD 353 [5] or the CDM [32], where the maximum number of risers in a single flight is set to 13 and 12, respectively.

The landings should be similar in width to the connecting flights. The minimum landing length is defined as the greater value of 2 m or the flight width in [5]; a length between 1.5 m and 2 m is prescribed for comfortable use (min 1 m if space is limited) in [32]; while in [21] a landing length of 1.2 m (0.8 m if space is limited) is recommended.

Risers and goings in a flight have to be uniform [5,20,32]; completely open risers are not allowed [5,17,20,32]. The prescribed dimensions of risers and goings are shown in Table 8.

Table 8. Dimensions of stairs in cm.

Reference	Riser (R)	Going (G)	G to R Relationship
CD 353 [5]	$R \leq 15$	$G \geq 30$	-
ODPCB [17]	$11.5 \leq R \leq 19$ (17.5 *)	25 (30 *) $\leq G \leq 35.5$	$55 \leq 2R + G \leq 70$ $R{:}G \leq 1{:}1.6$ ***
BDDM [21]	$R \leq 15$	-	-
ADA [20]	$10 \leq R \leq 18$	$G \geq 28$	-
SDM [32]	$R \leq 15$ (16.5 **)	$G \geq 28$ (25 *)	$58 \leq 2R + G \leq 60$ $420 \leq R \times G \leq 450$

*, for access to schools; **, if space is limited; ***, max slope of stairs is 62.5%.

The acceptable measurements for going and riser values are presented in Figures 8 and 9 for [17,32], respectively, in which relationships between the going and riser are given. Although in the SDM [32] the maximum going and minimum riser are not specified (Table 8), they can be determined from riser/going relationships (Figure 9).

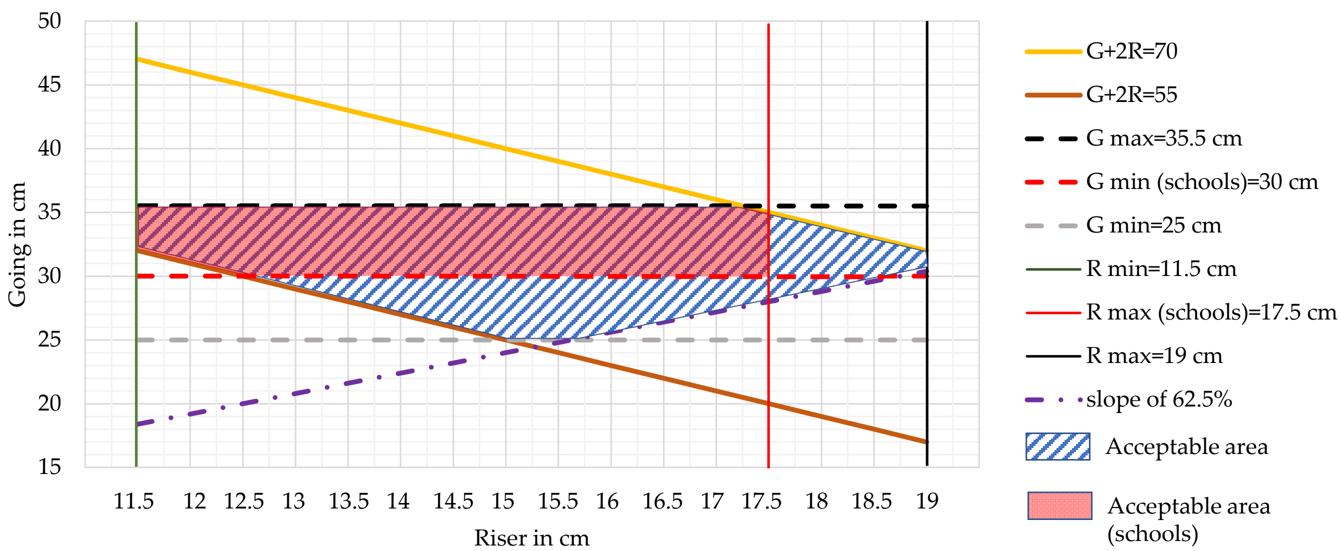

Figure 8. Acceptable measurements for the going (G) and riser (R), based on [17].

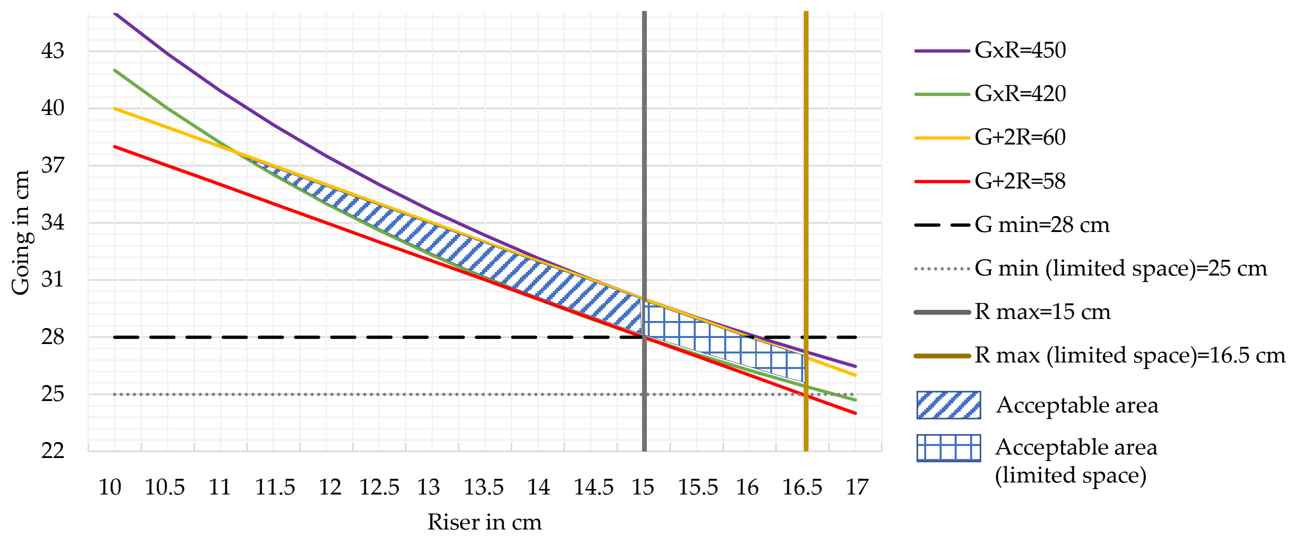

Figure 9. Acceptable measurements for the going (G) and riser (R), based on [32].

We recommend the following limiting values in the design of accessible stairways in the case of no space limitation: a riser between 11.5 cm and 15 cm, and a going between 30 cm and 35 cm. The recommended values for risers and goings are set as the values that meet all the requirements specified in Table 8. For less comfortable conditions (limited space or other conditions), the relative values shown in Figures 8 and 9 may be used.

Appropriate clear space on the walking/cycling/riding surface has to be provided. Clear space is generally known as the horizontal and vertical clearance (clear width and clear height/headroom, respectively). Clearances on bridges and walkways depend on the bridge's usage. Pedestrian bridges can be used not only by pedestrians but also by bicyclists and equestrians. The shared use of bridges by pedestrians and bicyclists is more common, though, than their combined use by pedestrians and equestrians.

The minimum widths of walkways according to [5,17,20,21,31,32] are presented in Table 9.

Table 9. Minimum clear width on walkways.

Reference	Pedestrian Use	Cyclist Use	Combined Use	
			Unsegregated	Segregated
CD 353 [5]	2 m *	-	3.5 m	4 m to 5 m **
ODPCB [17]	1.8 m	2 m (one direction) 3 m (two directions)	3 m	-
BDDM [21]	1.5 m 1.8 (recommended)	1.4 m (one direction) 2.4 m (two directions)	-	
RDG [31], ADA [20]	1.52 m	1.52 m	-	
SDM [32]	2 m	2 m	-	

*, or dimension based on pedestrian traffic and slope; **, depending on method of segregation.

It is important to note that the clear width of the walkway should be designed to accommodate the users. Therefore, in addition to the minimum dimensions given in Table 9, the number of users and the slope of the walking surface should also be considered when determining the clear width of a new bridge. If the bridge designer does not have information about the traffic conditions, the recommendation in [5] can be applied.

The minimum width of ramps and stairs is usually prescribed to be as wide as the connecting walkways [5,18,32], with the exception in [21] where the minimum ramp width for pedestrians is set as 1.1 m.

Vertical clearances differ for pedestrians, bicyclists and equestrians. The minimum clear height is between 2.03 m [18,31] and 2.6 m [32] for pedestrians and between 2.4 m [5] and 2.7 m [17,32] for cyclists. Detailed values of the required vertical clearances for new bridges are provided in Table 10.

Table 10. Clear height/headroom for new bridges.

Reference	Pedestrian Use	Cyclist Use	Equestrian Use
CD 353 [5]	2.3 m	2.4 m	2.7 m/3.7 m *
ODPCB [17]	2.4 m	2.7 m	-
RDG [31], ADA [20]	2.03 m	2.54 m	-
SDM [32] ***	2.3 m/2.6 m **	2.5 m/2.7 m **	-

*, dismounted/mounted; **, values for construction length of <23 m/≥23 m; ***, for enclosed bridges.

The values defined for vertical clearances on bicyclists' paths have to be applied to combined pedestrian–bicycle traffic as well. The headroom on maintained enclosed bridges may be reduced to 2.3 m for pedestrians only if the bridge is up to 23 m long; in other cases the headroom should be at least 2.5 m [32].

4. Conclusions

Building active travel infrastructure is one of the most important factors in promoting the transition from a car-oriented to an active travel society, thus contributing to the green transition. Pedestrian bridges, as part of active travel infrastructure, should be designed to be universally accessible to encourage people to use them.

Although in the last two decades much attention has been paid to the development of standards for the accessible design of buildings and other engineering structures such as roads, bridges, etc., there is a large number of pedestrian bridges worldwide that are avoided by pedestrians because they do not meet the requirements for comfortable use.

The construction of a universally accessible bridge may initially cost more, but if accessibility demands are carefully incorporated into the design, cost-effective solutions, often even cost-neutral solutions, can be found. This not only reduces construction costs, but also avoids the potential costs of retrofitting bridges to achieve accessibility.

This paper provides an overview, comparison and commentary on the most comprehensive current pedestrian bridge design standards, guidelines and manuals that contain information on accessible design. Special attention is given to the design of stairs and ramps as critical elements of bridge accessibility.

The accessibility design parameters described in this paper, which should be considered in the preliminary bridge design stage, can help engineers in different countries, especially in low- and middle-income countries, where there are not many resources but a large number of pedestrians and cyclists, to find an optimal design solution. They can also be used to assess the accessibility of existing pedestrian bridges and identify elements that do not meet the conditions for general accessibility.

The review presented in this paper was driven by the desire to raise awareness about the universally accessible design of pedestrian bridges among bridge designers, especially in countries where accessibility requirements are not part of the state's legislation.

Considering accessibility, along with other design parameters, will lead to a sustainable solution for pedestrian bridges in the long run.

Author Contributions: Conceptualization, I.Š.G.; methodology, I.Š.G. and I.V.; investigation, I.Š.G., I.V. and D.G.; resources, I.Š.G. and P.Š.; drawings, P.Š.; writing—original draft preparation, I.Š.G., D.G. and P.Š.; writing—review and editing, I.Š.G. and P.Š.; project administration, I.Š.G.; funding acquisition, I.Š.G. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the University of Rijeka, grant number "uniri-tehnic-18-127".

Data Availability Statement: Data are contained within the article.

Conflicts of Interest: Author Iva Vodopija was employed by the company iINVEST d.o.o. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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