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Review

Bicycle Infrastructure Design Principles in Urban Bikeability Indices: A Systematic Review

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Abstract: Bicycling is a sustainable form of micromobility and offers numerous health and environmental benefits. Scientific studies investigating bikeability have grown substantially, especially over the past decade. This paper presents a systematic literature review of the developed urban bikeability indices (BIs). The paper provides insight into the scientific literature on bikeability as a tool to measure bicycle environment friendliness; more importantly, the paper seeks to know if the BIs consider bicycle infrastructure design principles. Data extraction included identifying the geographical location, essential indicators, sample size and distribution, data source, the unit of analysis, measurement scale, methods used to weigh indicators, and identification of studies using bicycle design principles in BIs. The database search yielded 1649 research articles using different keywords and combinations, while 15 studies satisfied the inclusion criteria. The studies were found to be conducted in various geographical locations. The unit of analysis for developing the index varied across studies, from street segments or bicycle lanes to zones within the city or even the entire city. The most commonly utilized method in developing urban BIs was a scoring and weighting system to weigh the indicators. The weighting methods include an equal weight system, survey-based and literature review-based methods, expert surveys, the analytic hierarchy process, and a weighted linear combination model. The essential criterion is bicycle infrastructure, such as bike lanes, routes, and bicycle paths as 14 studies considered it for the construction of the BIs. The review findings suggest a lack of consideration of all five bicycle infrastructure design principles, as only three studies considered them all, while others only included a subset. Safety and comfort are the most commonly considered principles, while coherence is the least considered principles in the BIs. It is crucial to consider all five bicycle infrastructure design principles to create a bicycle-friendly environment and attract more people to this sustainable mode of transportation.

Keywords: sustainable mobility; micromobility; bicycling; bikeability; bicycle friendliness

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Citation: Ahmed, T.; Pirdavani, A.; Wets, G.; Janssens, D. Bicycle Infrastructure Design Principles in Urban Bikeability Indices: A Systematic Review. *Sustainability* **2024**, *16*, 2545. https://doi.org/10.3390/su16062545

Academic Editors: Leonardo Caggiani and Luigi Pio Prencipe

Received: 26 January 2024
Revised: 13 March 2024
Accepted: 15 March 2024
Published: 20 March 2024

1. Introduction

Cycling and walking are considered healthy and sustainable modes of transportation and are recognized and endorsed by governments worldwide [1,2]. Bicycles take up less road space and have zero carbon emissions compared to motorized modes of transportation, so their use in cities is primarily viewed as advantageous to the environment and air quality [3–5]. In the past, road officials emphasized motorized vehicles' safe movement, hence giving less attention to the green modes of transportation [6]. However, policymakers' paradigm has been shifted to provide and improve cycling quality to increase the share of this form of micromobility [6,7]. This necessity to shift travel choices from motor vehicles to eco-friendly bicycles is driven by traffic congestion, air pollution, and other transportation problems [8,9].

Cycling requires appropriate infrastructure, which is essential to its attractiveness [10]. For example, bike lanes are crucial for bicyclist safety and comfort [11]. Dedicated and protected bike lanes reduce the risk of crashes and injuries, as they provide separation from the roadway by means of physical barriers [12,13]. Similarly, bicycles need safe parking facilities, which are crucial for protecting bikes from theft and ensuring convenience for cyclists [14]. Studies show that current and prospective cyclists are willing to pay for better parking facilities to enhance their personal safety and protect their bikes from theft and vandalism [15]. Furthermore, bicycle signals may be required at junctions for cyclists to cross safely [16]. The absence of traffic signals increases the risk of accidents, as it leads to confusion and errors in judgment, contributing to a higher likelihood of road accidents [17]. At the same time, the lack of bicycling infrastructure and a supportive environment discourages bicycle use [2]. Well-planned bicycle infrastructure has the potential to increase bicycling share, as evidenced by research showing a rise in bicycle activity after implementing new infrastructure [11].

The viability of bicycling as a transport mode depends on the condition, comfort, and safety of the infrastructure [18,19]. Over the years, researchers and practitioners have developed several models to assess bike riders' experience. These bicycle infrastructure assessment methods are objective and subjective. Subjective methods assess perceptions gathered from surveys, interviews, or group discussions [20]. Direct observation using audits and geospatial methods using secondary data, such as geographic information systems and remote sensing, are objective tools that measure the physical characteristics of an environment [21]. Some of the most commonly used metrics are bicycle level of service (BLOS), the bicycle compatibility index (BCI), bicycle safety index rating (BSIR), bicycle suitability rating, CycleRap, and the bikeability index (BI) [6,7,16,21–24].

Bicycle assessment methods date back to the 1980s, when Davis [25] initially proposed aBSIR. Similarly, other methods have been developed to assess bicycle infrastructure using metrics such as level of service, quality of service, level of traffic stress (LTS), and the dynamic comfort index (DCI) [2,26,27]. The concept of bikeability existed before; however, the term bikeability has grown, especially in the last decade, because of the walkability concept [21]. Walkability and bikeability are directly related to the built environment, which affects the accessibility, safety, and comfort of pedestrians and cyclists. Although there are certain similarities between walkability and bikeability, a notable difference is in their evaluation. Bicycling requires equipment and a certain level of expertise to ride, and the significance of infrastructure over land use is more pronounced for cycling than walking [10]. The growth in the concept of bikeability encompasses both the increased use of the term and the evolution and refinement of the underlying concept over time. While planners have been working to improve the conditions for cycling for decades, the term "bikeability" may not have been widely used initially, and its recent prominence reflects a growing awareness and emphasis on creating environments that support and promote cycling. Table 1 summarizes different concepts and their essential considerations when developing the metrics in the literature to assess the bicycle environment.

Table 1. Methods for assessing bicycle environment.

Assessment Category	Relevant Assessment Tools	Important Factors	References
Vibration or Roughness Index	DCI, International Roughness Index, Dynamic Cycling Comfort, Bicycle Environmental Quality Index	Vertical acceleration Bicycle vibration	[2,19,28–30]
Bicycle Level of Service	BLOS, LTS, Quality of service, BSIR, Bicycle Comfort Level Rating	Infrastructure Geometric design Traffic conditions Traffic stress	[1,16,31,32]
Bicycle Safety Index	Bicycle Safety Index	Motorized vehicles (speed, volume, flow, density, and infrastructure)	[7,33]
Bikeability Index	BI, Area-Wide Bikeability Assessment Model (ABAM), Bike Score®	Safety Comfort Attractiveness Directness Coherence	[34–38]

Bikeability can be defined in different ways [39,40]. Bikeability measures how easy, safe, and convenient it is to ride a bike on a particular path or in a particular area [41]. Lowry et al. (2012) defined it as "an assessment of an entire bikeway network for perceived comfort, convenience, and access to important destinations." [22]. According to another definition, it is the extent to which the real and perceived environment are favorable and safe for riding [21]. Some scholars have attempted to explain the difference between bikeability and related concepts, such as bike suitability and friendliness [42]. Bicycle suitability is "an assessment of a linear stretch of a bikeway's perceived comfort and safety" [34]. Hence, bikeability is a superordinate term, both geographically and conceptually [42]. Similarly, bicycle friendliness includes characteristics of bikeability and refers to a community's assessment of many aspects of biking, such as laws and regulations, education initiatives, and cycling acceptance [42,43].

There has been rising interest in bikeability-related studies as the number of publications on the subject has increased dramatically, especially over the past four years. Exponential growth is seen in the number of published papers on "bikeability" since 2010, starting with 10 articles in WOS and 32 in Scopus that year. The number of publications on the topic consistently increased over the years, reaching a peak in 2021, with 72 articles in WOS and 124 in Scopus. The rising interest in bikeability-related studies over the years can be attributed to several factors. The increased awareness about active modes of transportation and the necessity for sustainable cities can be attributed to this uptick [6]. Using bicycles as a means of transport can help reduce traffic congestion, improve air quality, and lower carbon emissions [44]. Also, addressing cycling-related factors, such as safety and accessibility, is essential for promoting active transportation and public health [45]. Bicycle use also has health benefits, reducing the risk of all-cause mortality [46]. Bikeability intends to assess and integrate cycle infrastructure for individual well-being and promote urban environmental sustainability [6]. The growing body of literature in this area can help inform the creation of successful policies to increase cycling in cities. Hence, a comprehensive review of bikeability will be helpful.

Studies and discussions suggest that promoting bicycle use is critical for urban planning and transportation policy [47,48]. Cities and institutes have stressed that bicycle infrastructure design principles are essential elements that play a crucial role in promoting bicycle use [49]. Researchers have developed different tools that can be used to assess a city's or a neighborhood's bikeability—in other words, bicycle friendliness. In addition, diverse criteria, weighing systems, analysis units, and methods have been used to develop BIs. To facilitate a comprehensive review of bikeability tools, synthesizing and critically evaluating the existing literature is imperative.

Additionally, gaining insight into different aspects utilized in BIs is important. Moreover, a vital aspect of this review involves assessing whether urban BIs align with fundamental bicycle infrastructure design principles, such as safety, comfort, attractiveness, directness, and coherence. To inform policymakers about future bicycle planning initiatives and to extract, synthesize, and extend the existing body of knowledge for the scientific community, a comprehensive review of the literature that explores the links between bikeability indices and bicycle infrastructure design principles in these indices is needed yet currently missing from existing the literature to the best of our knowledge. A systematic review paper is presented because it ensures a rigorous and comprehensive synthesis of existing evidence, minimizing bias and providing a reliable foundation for informed decision-making in the targeted subject area [50].

1.1. Overview of the Bicycle Infrastructure Design Principles

People of different ages and cycling abilities should experience and enjoy the built environment [11]. It is understood that people's standards of what is "acceptable" differ, but the concept of "inclusive design" serves as the foundation for all bicycle infrastructure design principles [3,21]. Cycling-friendly infrastructure must meet five internationally recognized criteria: safety, comfort, attractiveness, directness, and coherence [49,51–53].

1.1.1. Safety

The perception of danger could discourage people from taking up cycling. Researchers have found a positive relationship between perceptions of safety and increased cycling [54]. Safety measures for a bicycle include, for example, the type of bicycle infrastructure, motorized traffic speed along a bicycle path, traffic control devices at junctions, street lights for evening and night-time cycling, and buffer space from car parking along the cycle path [35,49].

1.1.2. Comfort

Comfort refers to reduced physical exertion from riding a bicycle on a good network [35]. Bicycling comfortability can be achieved by providing a sufficient width for riders; providing minimal stopping and starting along cycle routes; minimizing steep grades; and, whenever feasible, reducing interaction with high-speed or high-volume motorized traffic. When the mentioned factors are considered, bicycle pathways or cycling routes create an environment that allows cyclists to travel efficiently and comfortably [55,56].

1.1.3. Attractiveness

Cycling is an enjoyable experience partly because of the close connection to the external environment [57]. The visual and aesthetic aspects of the built environment are referred to as attractiveness. This component includes trees and shade, scenery, cleanliness, quality of public open space, aesthetic buildings, and street furniture [58]. Selecting a bicycle as a transport mode depends on the attractiveness of cycling and competing modes such as the bus [59].

1.1.4. Directness

This criterion relates to minimizing traveling distance and time by taking the fastest route between the origin and destination and avoiding intersections or stoppages [60]. Directness is important, as cycling can be an appealing alternative to driving or public transportation, particularly for local journeys [6]. A good cycling route must be direct and eliminate the need for cyclists to undergo diversions [61].

1.1.5. Coherence

Bicycle cohesion (accessibility) is defined as people’s ability to reach their primary destinations via direct routes [62]. A bicycle network should connect all primary cycling origins and destination zones/centers. Cycle routes can be made cohesive by the continuity of bicycle routes and proximity to other transport modes for better connectivity [53].

The remainder of this paper is structured as follows. Section 2 describes the systematic methodology adopted for the study. Section 3 discusses the results of the study. Section 4 presents a discussion of the review findings. Lastly, Section 5 presents the study’s conclusions and limitations and the future scope of the work.

2. Methodology

We utilized the Preferred Reporting Items for the Systematic Review and Meta-Analyses (PRISMA) procedure for this review [63]. The technique aims to be robust and reproducible by minimizing possible biases in research reviews and transparent in choosing and categorizing papers based on precise eligibility criteria [50,64].

2.1. Search Strategy

The study approach began with identifying the topic, the scope of the work, the research aims, and the objectives. Then, a protocol was developed for the papers to be included in the review following the PRISMA method. We searched Scopus, Web of Science, and ProQuest to find the research papers. The initial search was conducted from February 2023 to March 2023 and updated in December 2023 to identify new studies. Before starting the search of the scientific databases, key concepts were developed to ensure we did not miss any relevant research. Possible synonyms, technical terminology, layperson's terms, acronyms, and abbreviations were considered. Concept 1 included bicycle-related keywords and phrases, such as "bike*", "bicycl*", "bicycl* infrastructure", "cycl* infrastructure", "bikeab*", and "bikeability". Concept 2, on the other hand, included terms like "index*", "assessment tools", "assessment methods", "evaluation criteria", "checklist", "compatibility", and "level of service", focusing on assessment-related terminologies to further narrow the search towards evaluation methods and criteria.

After selecting keywords, the key concepts inside each component were linked using "OR", while the two groups were linked using "AND". Suitable Boolean pairs such as "AND" and "OR" help to drastically reduce the number of results returned, as well as remove undesirable results [50]. The asterisk (*) function in search queries is used to include variations of words, effectively capturing terms like "bicycle“ and "bicycling“. Additional filters were also applied to narrow down the number of papers. The search queries and filters are mentioned in Table 2. We also performed forward and backward snowballing to identify missed papers while searching scientific databases.

Table 2. Search criteria.

Database	Search Terms	Filters	Articles Found
Scopus	((TITLE-ABS-KEY (bike*)) OR (TITLE-ABS-KEY ("Bicycl* infrastructure")) OR (TITLE-ABS-KEY ("Cycl* infrastructure")) OR (TITLE-ABS-KEY (bikeab*)) OR (TITLE-ABS-KEY (bicycl*)) OR (TITLE-ABS-KEY (bikeability)) OR (TITLE-ABS-KEY (blos))) AND ((TITLE-ABS-KEY (index)) OR (TITLE-ABS-KEY ("Assessment Tool")) OR (TITLE-ABS-KEY ("Assessment methods")) OR (TITLE-ABS-KEY ("Evaluation Criteria")) OR (TITLE-ABS-KEY (checklist)) OR (TITLE-ABS-KEY (compatibility)) OR (TITLE-ABS-KEY ("level of service")))	Language: English Publication period: 2010–2023 Article type: Journal and conference papers Exclude subjects like natural sciences, earth sciences, etc.	1048
Web of Science	((((((TI=(Bike*)) OR TI=(Bicycl*)) OR TI=("Bicycl* infrastructure")) OR TI=("Cycl* infrastructure")) OR TI=(Bikeab*)) OR TI=(Bikeability)) OR TI=(BLOS) AND ((((((((TI=(Index*)) OR TI=("Assessment Tool")) OR TI=("Assessment methods")) OR TI=("Evaluation Criteria")) OR TI=("Evaluation Criteria")) OR TI=(Compatibility)) OR TI=("level of service")) OR TI=(Assess*)) OR TI=(Evaluat*)	Language: English Publication period: 2010–2023 Article type: Journal and conference papers Exclude research areas like ecology, medicine, natural sciences, earth sciences, etc.	576
ProQuest	title(Bike*) OR title(Bicycl*) OR title("Bicycl* infrastructure") OR title("Cycl* infrastructure") OR title(Bikeab*) OR title(Bikeability) OR title(BLOS) AND title(Index*) OR title("Assessment Tool") OR title("Assessment methods") OR title("Evaluation Criteria") OR title(Checklist) OR title(Compatibility)	Language: English Publication period: 2010–2023 Source type: Conference papers and proceedings and scholarly journals Article type: Journal and conference papers	17
Forward and backward snowballing			8

2.2. Eligibility Criteria

The next step was to scrutinize and evaluate the papers to be included in the review. For this purpose, inclusion and exclusion criteria were defined (see Table 3). First, the articles had to be published in peer-reviewed journals or as conference proceedings. All other publications, such as research letters, book chapters, review articles, research notes, editors' comments, reader comments, and book reviews, were excluded. Further requirements for paper selection were that the paper was full-length and published in English after 2010.

Table 3. Inclusion and exclusion criteria adopted for the review.

Inclusion Criteria	Exclusion Criteria
• Research articles and conference papers • Published since 2010 • Full-length paper published in English • Considered only bikeability • The focus area must be an urban area. • Developed a method/tool/application for evaluating/assessing/measuring urban bikeability	• Hybrid methods • Measures only one aspect of bikeability • A method that does not come up with a composition of indicators into an index • Review articles, letters to the editor, opinion articles, book chapters, etc. • Full text not available to authors

The fourth criterion was to see if the paper considered methods for only bikeability. We did not consider hybrid methods that measure urban walkability and bikeability. Also, methods that only considered one aspect of bikeability, for example, bike lanes or bicycle surface quality, were excluded, since they do not provide a holistic picture of the urban bicycle environment. Also, studies with a focus other than urban areas, such as the BI for suburban or rural areas, were excluded, since the attributes that lead to higher or lower bikeability might differ. Lastly, studies should have developed a method, tool, or application for evaluating, assessing, or measuring urban bikeability.

In total, we found 1641 research records by searching three databases. In addition, we also identified 8 research articles based on "snowballing" not found in the initial search. Figure 1 shows the article identification, screening, and selection process. The identified records were imported into Rayyan for duplicate removal. Rayyan is a free web tool designed to assist researchers in managing the literature review process [65]. First, all duplicates (n = 116) found in the three searched databases were removed. After removing duplicates from 1533 articles, 1469 were excluded based on title-and-abstract screening. For the remaining 64 papers, full-text papers (n = 63) were retrieved and assessed against the eligibility criteria for inclusion or exclusion, as the authors failed to retrieve the full text of 1 research article. Forty-eight studies were ineligible, as they did not satisfy the eligibility criteria, i.e., they did not construct an index for the bikeability of an urban area or the scope of the study was outside an urban area. Similarly, some methods were hybrid, considering both walkability and bikeability. The remaining 15 articles were used for this systematic review and comprehensively synthesized to extract the results.

2.3. Data Extraction Process

Selected articles were scrutinized to extract relevant data and comprehensively understand their contents to answer the research questions. Table 4 shows the elements extracted against each category. The extracted information includes the author, year of publication, city, country, research instrument, data source, measurement scale, geographical location of the study, study design, unit of analysis, bikeability variables, and type of measurement. In addition, the retrieved variables were categorized and grouped to identify the studies using bicycle design principles in BIs.

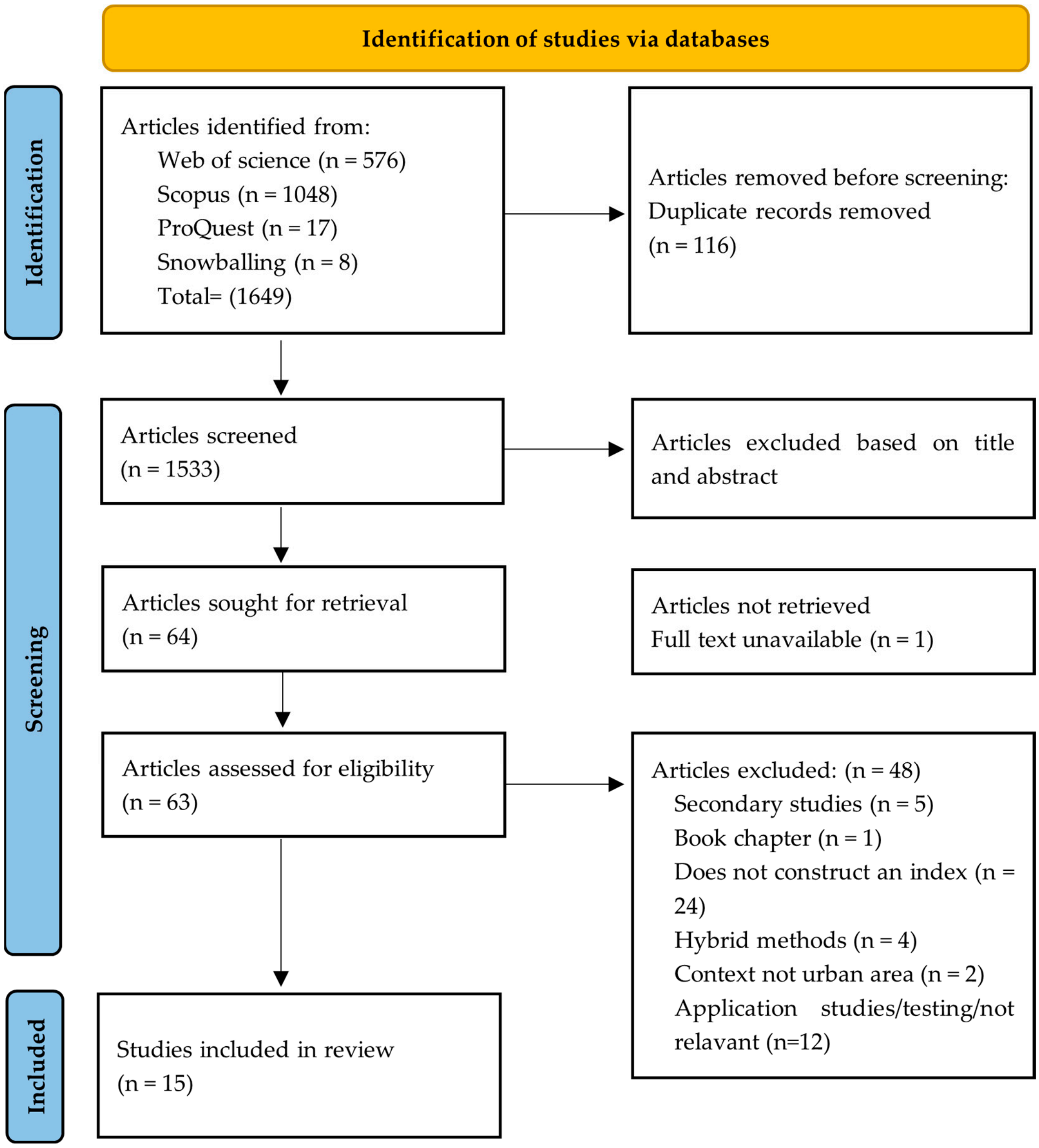


Figure 1. Systematic search process based on the PRISMA framework.

Table 4. Elements extracted during the systematic review.

Category	**Extracted Elements**
Identifying information	Author's name; title of the research article; publication year
Study setting	The geographical location; description of the study
Research design	Sample size; sample selection; characteristics of the population under study; age
Study methods and unit of analysis	Data source; unit of analysis; methods used; measurement scale
Critical variables	Number of variables considered; important variables
Bicycle design principles in BI	Grouping of indicators; identification of study using bicycle design principles in BI
Finding	Main results specific to BI; important variables that improve BI, other considerations for BI

3. Results

3.1. Geographical Location of the Studies

The studies included in this literature review were conducted in several countries worldwide, including Spain (n = 2) [66,67], Germany (n = 2) [42,68], Singapore (n = 2) [69,70], Greece [57], Japan [69], the United States [34], Colombia [35], Taiwan [36], Canada [71], Russia [22], Austria [72], and China [73]. Two studies were conducted across two countries (the United States and Canada, Singapore and Japan) [38,69].

3.2. Formulation of BI

The BIs offer a valuable tool for assessing how suitable an environment is for cycling. Authors have used various nomenclatures for BIs, such as the ABAM, BikeDNA, etc. [36,38]. The formulation of an index for urban bikeability is a multi-step process [35]. The first step is identifying criteria, such as traffic, safety, comfort, or connectivity [66,69]. For each criterion, a list of indicators is identified. These indicators can include but are not limited to the presence and condition of bike lanes, pavement quality, traffic volume and speed, connectivity, land use, topography, bike parking facilities, and bicycle-sharing systems [6]. The selection of indicators depends on the context of the BI; for example, micro-level indicators are selected to develop BIs for street-level assessment. Studies then assigned a score or values to these indicators. For example, a scoring system was used in developing Munich's BI [42].

The next step is assigning each indicator a weight based on its perceived importance in facilitating or hindering bikeability. Assigning weights involves population surveys, stakeholder consultations, expert judgments, or empirical research to reflect each factor's relative importance in an area's overall bikeability [35,36,68]. By combining these weighted indicators and the scores of indicators, the BI generates a single score that reflects the overall bikeability of a specific location. This final BI score allows for easy comparison between different areas and can be a valuable asset for urban planners seeking to promote cycling within their cities. Equation (1) shows one example of a BI [66]. In the equation, each criterion has a list of indicators that compute the relevant score, i.e., Ti, Ii, or Ci.

$$\mathrm{Bi} = (0.4 \times \mathrm{Ti}) + (0.15 \times \mathrm{Ii}) + (0.15 \times \mathrm{Ci}) + (0.1 \times \mathrm{Pi}) + (0.2 \times \mathrm{Si}), \tag{1}$$

whereas

Bi = bikeability index
Ti = Traffic indicators
Ii = Infrastructure indicators
Ci = Connectivity indicators
Pi = Parking space indicators
Si = Topography indicators.

Equation (2) is another example of a BI developed to measure the mobility of biking in Mediterranean cities [67].

$$\mathrm{BI} = \alpha \mathrm{P} + \beta \mathrm{C} + \gamma \mathrm{L}, \tag{2}$$

whereas:

P: average of the parameters of the segment
C: number of cyclists in the segment
L: length of the studied segment.
α, β, γ: coefficients associated with the variables.

3.3. Study Demographics and Sample Size

The sample characteristics varied, with some studies using small sample sizes while others used larger sample sizes. The minimum sample size was 10 respondents [36,42], while the maximum number of respondents to a bikeability survey was 1402 [71]. One study did not disclose the sample size and characteristics [67]. The data were collected from the urban population and tourists. In contrast, three studies did not collect data from respondents, and they were either based on other methods, such as BLOS and bike suitability, or objective methods [22,38,73].

A few studies also reported the gender distribution. In the studies that disclosed the respondents' genders, men were predominant; only one study had more female respondents than men [72]. Only three studies reported the age distribution of the sample population, with one study considering respondents only under 45 years of age [57], while the other study considered respondents in the range of 18–65 years of age [34]. In another study, 40% of the participants were younger than 35 [72].

Only one study consulted experts to weigh bikeability indicators, with a majority of experts from Germany (58%), followed by other European countries (23%) and America (19%) [68]. In addition, most of the participants were researchers (77%), while the remaining 23% worked in practice. Two studies used focus group discussion and opinion surveys [34,71]. Also, two studies reported using actual travel behavior data [71,72].

3.4. Methods Used to Develop BIs

Table 5 provides information on the unit of analysis and method used for the development of the BI in selected studies. A scoring and weighting system was the most common method to assess urban bikeability. Of the 15 studies, 7 used a scoring and weighting system [35,42,66–68,71,72]. In the scoring method, the indicators of the BIs are given points against a well-defined point score system. The studies usually included complete guidelines based on the standard for each indicator. An audit tool is usually used to collect field data for each bikeability indicator, which are then compared with the guidelines, based on which a score is assigned. The studies used scores from 0 to 1; a score of 0 represents a bikeability indicator that does not exist at all, while a score of 1 shows that the indicator is present according to the standard [35]. Some studies used scores to define if a bikeability component is bicycle-friendly or unfriendly [72]. The second essential component of point-scoring BIs is weighing individual indicators. Usually, each indicator's weight is assigned based on user opinion surveys or experts [35,68]. In addition, the system applies to both individual street segments and grid cells [35,71]. The overall bikeability result is also measured in terms of points, i.e., 0–1 or 0–100, with lower points meaning less bikeable, while the higher points mean more bikeable [35,38,73].

Table 5. General characteristics of the selected studies.

Paper ID	Authors	Country	Data Source	Unit of Analysis	Method	Sample Size	Sample Characteristics
1	Codina et al. (2022) [66]	Spain	Local bike-user self-reported survey	100 × 100 m scale City level	Scoring and weighting	290	DNM *
2	Karolemeas et al. (2022) [57]	Greece	Digital Elevation Model, Open Street Map, existing traffic studies, and General Urban Plan	Street segment	Spatial analysis and AHP	15	12 men 3 women 90% under 45 years old and highly educated
3	Hardinghaus et al. (2021) [68]	Germany	Open geodata, expert surveys	City level	Scoring and weighting	57	37 men 20 women 58% of respondents from Germany 23% from other European countries 19% from America 77% professionals 23% researchers
4	Ito and Biljecki (2021) [69]	Singapore and Japan	SVI, surveys, OpenStreetMap (OSM), land use (LU), Digital Elevation Model (DEM), and Air Quality Index (AQI)	Street segments	Street view imaginary and computer vision	800	DNM

Table 5. *Cont.*

Paper ID	Authors	Country	Data Source	Unit of Analysis	Method	Sample Size	Sample Characteristics
5	Schmid-Querg et al. (2021) [42]	Germany	Field observations and interviews/questionnaires	Road segments and intersections	Scoring and weighting	10	DNM
6	Tran et al. (2020) [70]	Singapore	Land use maps Road network Land use regression Spatial analysis	Road segments	Objective approach	NA	NA **
7	Porter et al. (2020) [34]	United States	Internet-based self-reporting questionnaire, focus group discussion	City level	Exploratory factor analysis	998	520 men 409 Female Mean age: 38 (18–65 considered for data collection) Graduate degree: 33.4% College degree: 43.8% Below college: 22.8%
8	Arellana et al. (2020) [35]	Colombia	Survey questionnaire, secondary data, Google Street view	Road segments	Scoring and weighting	336	208 men 128 women 62.5% belong to socioeconomic strata 1 and 2, 26.5% to strata 3 and 4, and 11% to strata 5 and 6.
9	Ros-McDonnell et al. (2020) [67]	Spain	Secondary data	Bike lanes/roads divided into segments of 100–500 m	Scoring and weighting	DNM	DNM
10	Lin and Wei (2018) [36]	Taiwan	Literature reviews and stakeholder interviews	Zones	Analytic network process	10	DNM
11	Winters et al. (2013) [71]	Canada	Opinion survey Travel behavior Focus groups	10 m grid cells	Scoring and weighting	1402	DNM
12	Lowry et al. (2012) [22]	Russia	Secondary data and primary data on variables, if not maintained previously	Zones	BLOS and bike suitability	NA	NA
13	Krenn et al. (2015) [72]	Austria	Bike trips, questionnaire survey data	100 m × 100 m cells	Scoring and weighting	113	Men: 45% Women: 55% Age <35 years: 40% Age 35–40: 40% Age >51: 20%
14	Winters et al. (2016) [38]	United States and Canada	Secondary data	City level	Weighting and regression	NA	NA
15	Dai et al. (2023) [73]	China	Digital elevation model, Mobile phone signaling data, street view imagery, climate datasets	Road segments	Spatial and temporal analysis	NA	NA

* DNM: Did not mention, ** NA: Not applicable.

One study used the Analytic Hierarchy Process (AHP) [57]. The method involves five steps, as follows: defining indicators, determining parameters, developing scoring rubrics, weighting each parameter using the AHP, and generating a bikeability map for the case study. Another study used street view imagery and computer vision with extracted indicators [69]. The method uses six data sources, i.e., street view imagery, surveys, OpenStreetMap data, land use, a digital elevation model, and air quality index. The indicators are grouped into five categories (connectivity, environment, infrastructure, perception, and vehicle–cyclist interaction). An index called the composite index was proposed, and the critical aspect is that it uses an equal point system for the selected indicators in the index.

An objective approach was also utilized to develop a BI in [70]. The proposed BI was based on four subcriteria, as follows: air quality, accessibility, suitability, and perceptibility. Indicators were identified for all the subcriteria. Interestingly, an objective method was used to measure all the indicators, contrary to other bikeability indices in the literature. In developing a BI, one study used an exploratory factor analysis [34]. To identify and shortlist critical factors that would later be included in the index, an observational, cross-sectional study was conducted to assess multi-level ecological factors and their association with bicycling behavior. A self-reported Internet-based questionnaire assessed the proposed ecological factors of bicycling behavior. The concepts were shortlisted from the literature review, and focus groups were conducted at the two study locations to determine the factors necessary for adopting and maintaining bicycling behavior. The information obtained from literature and focus groups was used to draft an initial survey, which was then rectified after the pilot test. After data collection, the BI creation process involved the following steps: (1) determining the need for domain-specific indices through Spearman rank correlation coefficients; (2) identifying appropriate buffer sizes for environmental variables based on Spearman rank correlation coefficients; (3) conducting a Kaiser–Meyer–Olkin test and exploratory factor analysis to identify essential environmental factors; (4) using factor loadings to create domain-specific indices, ensuring the fit criteria of loadings, the absence of cross-loading, and the presence of at least three variables; (5) evaluating the association between domain-specific bikeability indices and bicycling frequency through correlation coefficients, stratification, and regression analyses, adjusting for clustering by study site and covariates.

One study introduced a BI called the ABAM using an analytic network process (ANP) method [27]. This study adopted the same approach as [34] in shortlisting assessment criteria. However, stakeholders were interviewed instead of cyclists to refine the initial criteria. The ABAM utilizes gray numbers to account for diverse performances within zones, ranking them based on identified interdependent criteria. Another study used the BLOS to determine the bikeability of the bikeway street network [22]. The first step to develop the BI was to calculate the BLOS for the bikeways in the study area. The resultant BLOS score can be used for a set of destinations to assess its bikeability, for example, the bikeability to public parks or commercial destinations. The multinomial logit mode choice model has also been used to determine a BI [68]. BI development was carried out in three steps. A literature review was conducted to identify bikeability indicators, and the expert survey was used to establish a weighting. Finally, an extensive spatial BI was developed by combining the established categories using OpenStreetMap data.

One study used the following four sub-indices to construct a BI: safety, comfort, accessibility, and vitality [73]. It utilized open-source data, advanced deep neural networks, and GIS spatial analysis to eliminate subjective evaluations and provide a more efficient and comprehensive evaluation of bikeability. The weights of each indicator were assessed based on principal component analysis. Another study developed a BI to gain insight into the elements that shape the behavior of residents' cycling activities by using machine learning, deep learning, and trajectory mining algorithms on large, multi-dimensional datasets [73]. The utilized datasets encompass a variety of sources, including bike-sharing trajectory data, digital elevation models, mobile phone signal data, points of interest, street view imagery, air quality monitoring data, and ERA5 climate datasets.

3.5. Unit of Analysis

The unit of analysis varied from the city level to street segments, intersections, and zones. Seven studies developed the BI for street segments or bicycle lanes [35,42,57,67,69,70,73]. The length for which the data were extracted/collected differed in these studies; for example, one study used 500 m aggregation for connectivity indicators and 100 m aggregation for some indicators, i.e., road width and presence of on-street parking [69]. Few studies considered data for the entire segment (road or lane) [35,42,57].

Another study considered bikeability for intersections, and the same indicators were used for intersections and road segments [42]. A bikeability method was also developed for bike lanes/roads [67]. However, the lanes were divided into segments of 100–500 m for better results and a more accurate and detailed assessment of the bikeability of a given segment. Four studies used a scale as the unit of analysis for the bikeability of urban areas [38,66,71,72]. The scale varied from 10 m [71] to 100 × 100 m [66,72], meaning they analyzed bikeability at a very granular level. Two studies considered bikeability in zones within a city [22,36]. In contrast, the remaining two studies considered bikeability at the city level [34,68].

3.6. Summary of the Bikeability Assessment Tools

Table 6 provides a synthesis of indicators affecting bikeability in urban environments, the crucial indicators considered, their assessment methods, and the research findings of each BI. One BI is based on a survey and literature review to identify challenges and hotspots in the built environment [66]. Another BI employs the analytic hierarchy process to evaluate ten indicators, such as slope and junction density, to demonstrate that the road network is the most influential factor in bikeability [57]. Experts were consulted in one study to rank the significance of five indicators [68]. The results indicated that biking facilities along main streets are emerging as the most pivotal element.

Another study used a spatial value index, infrastructure, perception, and vehicle–cyclist interaction to identify 34 indicators that explain more than 65% of the spatiotemporal mobility pattern [69]. Constructing a BI showed that bicycle infrastructure and speed limits are the most critical criteria for bikeability [42]. An index was also developed using a weighted linear combination model, and 12 indicators, including air quality, were combined to calculate the BI [70]. Moreover, exploratory factor analysis was conducted, and it was found that objectively measured environmental variables are more associated with bicycling for transportation and transportation bicycling frequency than with recreation bicycling [34]. Finally, one study used survey data and discrete choice models to rank 20 indicators and found that security is the most critical factor for frequent cyclists whose travel purposes are work and shopping [35].

Table 6 also provides information on different methods of weighting indicators used in BI studies. The weighting methods include an equal weight system, survey-based and literature review-based methods, expert surveys, the analytic hierarchy process, and a weighted linear combination model. These methods determine the relative importance of different indicators in a study or analysis. Some methods, such as exploratory factor analysis and rank survey data using discrete choice models, focus on statistical techniques for the weighting of indicators. Other methods, such as pairwise comparisons through an analytic network process and focus group discussion-based weights, involve subjective input from experts or stakeholders to determine the relative importance of different indicators. Survey-based and equal-weight systems are the most common methods used in BI studies to weigh indicators. Table 6 also provides an overview of the significant findings reported by the studies included in the review.

Table 6. Key indicators, weighting system, and findings of the selected studies.

Paper ID	No. of Indicators	Key Indicators	Weighting System for Indicators	Findings
1	10	Collisions involving bicycles; cyclist volume; nearest cycle path; nearest cyclable lane; intersections of cycle paths; intersections of cyclable lanes; intersections of cyclable paths and cyclable lanes; distance to biking stations; distance to bike racks; percent rise	Survey-based: Findings from the literature review	The proposed index helps show problematic areas. Predicting how often people will cycle. People living in places with more built environment features are more likely to ride.
2	10	Slope; junction density; traffic density; traffic speed; natural environment; built environment; centrality; activity coverage; accessibility to public transport stations; accessibility to bike-sharing stations	Analytic hierarchy process	Two-level hierarchy model. In Level 1, the road network is the most dominant factor. In Level 2, slope and junction density are the most critical factors. Accessibility to bike-sharing stations is the least essential factor.
3	5	Prevalence of neighborhood streets; street connectivity; biking facilities along main streets; green pathways; other cycling facilities	Expert survey-based weights	Biking facilities along main streets are the most crucial component of bikeability. In order of importance, the crucial indicators are street connectivity, the prevalence of neighborhood streets, and green pathways.
4	34	Connectivity No. of intersections with lights; No. of intersections without lights; No. of culs-de-sac Environment Slope; No. of POIs; Shannon land use mix index; air quality index; scenery—greenery; scenery—buildings; scenery—water Infrastructure Type of road; presence of potholes; presence of street lights; presence of bike lanes; No. of transit facilities; type of pavement; presence of street amenities; presence of utility poles; presence of bike parking; road width; presence of sidewalks; presence of crosswalks; presence of curb cuts Perception Attractiveness for cycling; spaciousness; cleanliness; building design attractiveness; safety as a cyclist; beauty; attractiveness for living Vehicle–Cyclist Interaction No. of vehicles; presence of on-street parking; presence of traffic lights/stop signs; No. of speed control devices	Equal weight system	Street view imagery (SVI) can be used to explain more than 65% of the spatiotemporal mobility pattern. The computer visiontechniques and SVI can be used to assess bikeability within and among cities.
5	4	Existence and type of bike path; speed limit; parking facilities for bicycles; quality of intersection infrastructure for bicycles	Survey-based weighting	Bicycle infrastructure is the most fundamental criterion, followed by the speed limit.
6	12	Leisure; transport; commercial; daily route; slope; sinuosity; bike route; greenery; crowdedness; outdoor enclosure; $PM_{2.5}$; BC	Weighted linear combination model	The inclusion of air quality makes a significant difference in calculating bikeability. Air quality, green spaces, and multiple land-use patterns should be improved in low-bikeability areas to enhance cycling mobility.
7	15	Bicycle lanes; separated paths; bicycle sharrows; protected bicycle lanes; bicycle signage; residential density; population density; ozone level; particulate matter; culs-de-sac; intersection density; highway density; distance to transit; parks; tree canopy coverage	Exploratory factor analysis	Environmental variables are not substantially correlated with recreation bicycling. The environmental variables are more significantly associated with bicycling used for transportation.

Table 6. *Cont.*

Paper ID	No. of Indicators	Key Indicators	Weighting System for Indicators	Findings
8	23	Presence of bicycle infrastructure; quality of bike path pavement; obstacles on bike paths; slope of bike paths; width of bike paths; presence of trees; aesthetics of buildings; presence of bicycle infrastructure; presence of traffic control devices; bus traffic flow; vehicle traffic flow; motorcycle traffic flow; pedestrian traffic flow; motorized transport; speed; presence of police officers; presence of security cameras; bike traffic flow; lightning; criminality on roads, directness and coherence; climate; cost of trip	Rank survey data; discrete choice models	Security is the most critical factor for frequent work and shopping cyclists. Bicycle infrastructure is the most crucial factor for sport cyclists. The slope of bike paths is one of the least essential components for comfort.
9	6	Conflicts with other modes of transport; mobility and urban road crossing; obstructions in mobility segments; safety in mobility; signaling and lighting of the bike lane; connection and distribution	Equal-weight system	The BI can identify disparity in situations along the bicycle lane.
10	25	Bikeway density; bikeway width; bikeway exclusiveness; bike parking space density; sidewalk width; sidewalk pavement; parking space for cars/scooters; arcade density; shoulder width, traffic volume; bus route; law enforcement; transit service; public bike service; public bike unavailability; tree shade; green space; air quality; slope; smooth traffic; conflictless traffic; night lighting; intersection density; bikeway ratio; mixed land use	Pairwise comparisons through analytic network process	Hilly terrain negatively affects bikeability. Intra-district biking travel could promote better satisfaction for bikers than inter-district biking travel. Bikeable districts contain large parks and good biking and pedestrian facilities.
11	5	Bicycle route density; bicycle route separation; connectivity of bicycle-friendly streets; topography; destination density	Focus group discussion-based weights	A significant positive correlation exists between the proportion of bicycle work trips and the bikeability score.
12	10	Outside lane width; bike lane width shoulder width; proportion of occupied on-street parking; vehicle traffic volume; vehicle speeds; percentage of heavy vehicles; pavement condition; presence of curbs; number of through lanes	Weighted as adjustment factors	Bikeability increased for the following three scenarios: (1) Adding new bike lanes to the community; (2) Adding new shared-use pathways; (3) Adding both new bike lanes and shared-use pathways.
13	5	Cycling infrastructure; presence of separated bicycle pathways; main roads without parallel bicycle lanes; green and aquatic areas; topography	Equal weight system	Regular cyclists live in more bicycle-friendly neighborhoods than non-cyclists. There is a positive relationship between the BI and cycling behavior. Cycling infrastructure, bicycle pathways, and green areas were positively related, and main roads and topography are negatively related to the used route.
14	4	Bike lanes; hills; destinations and road connectivity; bike commuting mode share	Unequal weight system	Census tracts with the highest bike scores (90 to 100) have mode shares 4.0 higher than the lowest bike score areas (0–25). Bike score correlates moderately with journey-to-work cycling mode share at the city level (r = 0.52) and the census tract level (r = 0.35).

Table 6. *Cont.*

Paper ID	No. of Indicators	Key Indicators	Weighting System for Indicators	Findings
15	13	Wind speed; slope; precipitation; temperature; sky view index; green view index; sinuosity; $PM_{2.5}$; average speed; public transport; commercial accessibility; number of trajectories; crowdedness	Principal component analysis	Elevated safety, accessibility, and vitality in areas result in higher bikeability scores. Traffic congestion, which lowers cycling speed and actual bikeability, is a potential downside of the higher vitality levels.

3.7. Important Variables Considered in the BIs

Usually, BIs comprise several variables that contribute to the overall score. The systematic review indicated that the essential criterion is bicycle infrastructure, such as bike lanes, routes, and cycle paths, as 14 developed BIs considered it. Only one BI did not consider the presence of bicycle lanes or paths because the BI was based on spatiotemporal bikeability using big data. Topography and trees or greenery along the bicycle path/lane were considered the second most crucial variables in calculating the BI, as mentioned in nine studies. The use of the presence of trees or green areas as an indicator underlines the importance of a pleasant and stimulating environment for cyclists. The city's topography or slope along bicycle paths significantly impacts cyclists' comfort, underscoring the importance of the physical effort needed for biking. Other essential components include traffic density on roads or at intersections (seven studies), vehicular traffic flow (seven studies), availability of street lights (six studies) and access to transit facilities (six studies). Five indicators were used in five BIs. These indicators are bicycle parking facilities; connectivity; traffic speed; safety and security; and density, such as population, residential, or arcade. Bicycle lane width, land use, conflicts, traffic control devices, and aesthetics of the buildings were used in four BIs.

Additionally, ten indicators, i.e., road width, the presence of sidewalks, road signage, pavement condition, parking facilities for vehicles, centrality, particulate matter, road signage, intersections, bike path density, and cyclist volume, were used in at least three BIs. Nine indicators were used at least twice. These indicators include crowdedness [70,73], culs-de-sac [34,69], curbs [22,69], and bicycle path obstacles [34,67]. Other less common indicators in BIs were only considered by one study. Some of these less frequently considered indicators include the ozone layer [34], utility poles [69], activities coverage [57], wind speed [73], and crimes [35].

After identifying the indicators used in developing the BIs, grouping them into five bicycle design principles was necessary. Indicators can be represented by one or more bicycle design principles. Based on the systematic review, all 181 indicators were narrowed down, since some were used with different names although measuring the same feature, such as grade and slope (see Appendix A). The indicators in the BIs were grouped into five bicycle infrastructure design principles. Figure 2 displays the indicators associated with each bicycle design principle.

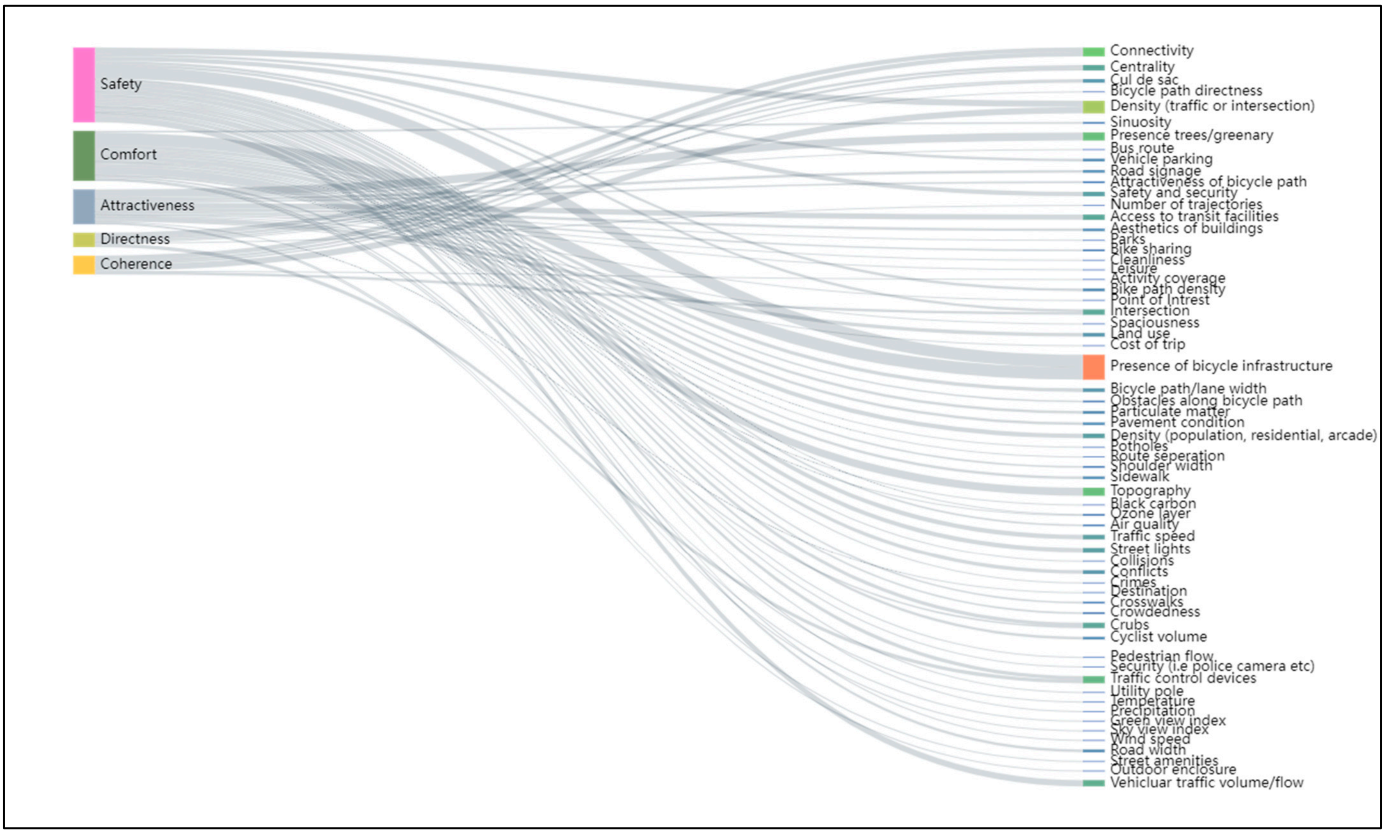


Figure 2. Relevant variables in bikeability design principles.

3.8. Bicycle Infrastructure Design Principles in the BIs

Bikeability assessments are generally based on the following five bicycle infrastructure design principles: safety, comfort, attractiveness, directness, and coherence [74]. These factors can be represented by a collection of components that are properties of each factor [35]. Table 7 shows the BIs developed by various researchers considered in this review. The table provides an overview of the BI studies considering at least one indicator from each of the five bicycle infrastructure design principles. It is evident from Table 7 that only three studies considered all the indicators from the design principles, while others only included a subset. For instance, one BI only considers safety, coherence, and comfort, while some consider all five principles [35,66].

Safety and comfort are the most commonly considered principles, directness and attractiveness are less commonly considered, and coherence is the least considered principle in the studies. Three BIs only considered the following two bicycle infrastructure design principles: safety and comfort [42,67,73]. Based on Table 7, it is clear that the bicycle infrastructure design principles considered in constructing a BI vary across different studies. However, for a comprehensive and holistic assessment of bikeability, it is recommended to consider all five principles, as each contributes to the creation of a safe and attractive cycling environment. Therefore, future studies should develop a BI incorporating all indicators for a more comprehensive bikeability assessment.

Table 7. Synthesis of BIs according to bicycle infrastructure design principles.

Paper ID	**BI Index Categories**				
	Safety	**Comfort**	**Attractiveness**	**Directness**	**Coherence**
1	✔	✔			✔
2	✔		✔		✔
3		✔	✔	✔	
4	✔	✔	✔	✔	✔
5	✔	✔			
6		✔	✔	✔	
7	✔	✔	✔	✔	
8	✔	✔	✔	✔	✔
9	✔	✔			
10	✔	✔	✔	✔	✔
11	✔	✔			✔
12	✔	✔			
13	✔	✔	✔		
14	✔	✔	✔		
15	✔	✔	✔	✔	

✔ (Considers at least one indicator).

4. Discussion

The authors comprehensively reviewed various methods and approaches developed for bikeability indices in urban environments. The review findings show that a scoring and weighting system was the most commonly used method for the assessment of urban bikeability. This method is most popular because it offers a systematic and easy-to-follow approach to constructing BIs [35,72]. This approach is utilized in similar research, i.e., BLOS and walkability index research [24]. However, the scoring and weighing system has critics [27]. For example, some BIs used an equal weight system, which is often criticized because the indicators do not affect the index equally [24]. To overcome this problem, studies have used questionnaire surveys to find the weight or importance of indicators [35,71].

For weighing indicators, a sample size that is significant enough is required to ensure the collected data accurately represent the population of interest [74]. Nonetheless, one study used a small sample size to construct an indices and surveyed only ten bicyclists [42]. A small sample size can lead to biased and mostly unreliable conclusions that may not represent the broader population [10]. The importance of variables in BIs based on a smaller size raises concerns about their generalizability, which limits their applicability.

Interestingly, only one study consulted only experts to weigh bikeability indicators, which may suggest a lack of expert involvement [57]. Asadi-Shekari et al. (2019) stated that expert surveys can help researchers ensure that the most important indicators are considered [20]. However, there are also potential drawbacks to relying solely on expert surveys. Experts may have biases that can influence their perceptions, and their opinions may not necessarily reflect the preferences and needs of the users. Therefore, a balanced approach that combines expert surveys with other methods, such as community surveys, can help overcome these limitations [65]. Ahmed et al. (2021) suggested using the mixed approach and argued that this could provide valuable insights in selecting effective indicators [24].

The BIs used various methodologies to collect data, mainly conducted through field surveys or reliant on data provided by government departments or other secondary sources [34,35,69]. This approach is usually time-consuming and requires human and financial resources, while the data may be outdated due to recent developments if relying on secondary sources. Recent BIs have utilized emerging technologies and data sources, including remote sensing images, virtual auditing through SVI, and crowdsourcing, for data collection [36,71–73]. This approach can be more standardized and scalable but comes with technical difficulties in the implementation stage. In addition, remotely sensed imagery cannot capture micro-scale street-level information.

Another crucial finding is that the unit of analysis for the development of the indices varied across studies. Some BIs focused on street segments or bicycle lanes, while others considered intersections, zones within the city, or even the entire city. This variability in the unit of analysis is essential to consider, as it can impact the accuracy of the BI. For example, studies analyzing bikeability at a very granular level, such as 10 m or 100 × 100 m, can provide a more detailed and accurate bikeability assessment for a segment or area [66,72]. In contrast, studies focusing on the city level may not capture the nuances of bikeability in different neighborhoods or streets. Deciding on the BI for a specific context is essential; if street-level bikeability is needed, the BI method developed by Arellana et al. (2020) is very appropriate [35]; however, if macro-scale bikeability of the city is required, the methods developed by Codina et al. and Lin and Wei are beneficial [36,66].

The systematic review results show a lack of uniformity in the number and types of indicators considered for the BIs. The number of indicators considered varied significantly between studies, ranging from 4 [38,68] to 34 [69]. This disparity can make comparing bikeability indicators and scores across different cities challenging, as the indicators' definitions and metrics differ widely. However, the most commonly considered indicators are bicycle infrastructure, greenery along bicycle paths, slopes, vehicular traffic flow/volume, street lights, bicycle path connectivity, and traffic speed. These indicators are related to the sense of comfort and safety along the bicycle pathways, which, when offered, results in a preference of people to choose bicycles over other modes of transport [75]. Past research shows that other indicators, along with cycle infrastructure, such as pavement conditions, road markings, traffic control devices, and crosswalks, play a significant role in getting people to ride bikes [7,76]. However, few studies have considered these essential indicators. Therefore, these indicators need more attention while measuring bikeability, as they can significantly affect rider experience and safety. Furthermore, this review highlights the importance of selecting appropriate indicators for the local context. For instance, indicators like the ozone layer and particulate matter may not be relevant for all cities. In contrast, variables such as motorcycle flow or the presence of police officers may be more crucial for some cities, like cities in the global south [35]. Therefore, it is essential to consider the local context while selecting indicators for BIs.

Studies have developed BIs to assess the quality of cycling infrastructure, but no consensus exists as to which indicators should be included [10,21]. Moreover, the review results suggest a lack of consideration of all five bicycle infrastructure design principles—safety, comfort, attractiveness, directness, and coherence—in developing existing indices. However, these five elements of cycling infrastructure design are universally agreed to promote bicycling [11,53]. Still, the existing indices focus on only a subset of these principles, with safety and comfort being the most commonly considered ones. Zhao et al. (2018) conducted a study in Beijing and Copenhagen to adapt bicycle design solutions and recognized the significance of all five principles [53]. They found that good bicycle infrastructure design always encourages people to cycle.

In this systematic review paper, we found three studies that considered all five design principles of bicycle infrastructure. However, it should be noted that one study was conducted in the global south, and it may not be directly applicable to other regions [35]. The other two are complicated methods and require technical knowledge in their applicability [36,69]. Thus, there is a need to develop a new, easy-to-follow BI that incorporates all indicators from the five design principles for a more comprehensive assessment of bikeability. This new index would provide a more accurate picture of the quality of cycling infrastructure, helping policymakers and urban planners prioritize investments that lead to safer and more attractive cycling environments.

5. Conclusions and Recommendations

Worldwide, the use of micromobility vehicles is significantly increasing in cities. Bicycling is a sustainable micromobility mode. In the past decade, there has been a rising interest in bikeability-related studies, reflecting a growing awareness of sustainable mobility.

Through this systematic review, we wanted to identify the essential indicators covered in bikeability studies. The result indicates that bicycle infrastructure is the most commonly considered indicator in bikeability assessment methods, underscoring its critical role in promoting cycling as a viable and preferred mode of transportation. It is followed by indicators such as trees or greenery along the bicycle path/lane and bicycle comfort factors like slope. Other crucial bikeability indicators include bicycle parking facilities, bicycle path connectivity, vehicular traffic volume, traffic speed, intersection density, and road signage. The critical indicators identified in this review will help urban planners and policymakers to plan well-designed bicycle infrastructure. This will facilitate safer and more efficient travel for cyclists and reduce congestion and pollution from motor vehicles, aligning with broader environmental and public health goals.

BIs are a vital tool in assessing the friendliness of urban settings towards cyclists, encompassing various levels, i.e., street segments to city-level assessment. However, a few issues were identified, such as some BIs using a small sample size for weighing of the index indicators. The second issue found was that there is no consensus on the number of indicators used in BIs. Studies have used from 4 to 34 indicators. Another critical research question was whether urban BIs consider bicycle infrastructure design principles. Since governments and researchers agree that five bicycle infrastructure design principles should be considered to make bicycles an attractive mode for medium and short trips in urban areas, we categorized the indicators used in the studies into safety, comfort, attractiveness, directness, and coherence. The results suggested that the safety and comfort components of bicycle infrastructure were the most commonly considered principles, while coherence was the least considered. However, for a comprehensive and holistic assessment of bikeability, it is recommended to consider all five design principles. Each principle contributes to the creation of a safe, comfortable, and attractive cycling environment, which is crucial for the promotion of cycling and the improvement of infrastructure.

The findings of this literature review emphasize the importance of accurately analyzing bikeability to encourage cycling and enhance infrastructure. This review also highlights the need for a comprehensive and easy-to-follow approach that considers all design principles and emphasizes the importance of a sufficient sample size in data collection. Future studies should aim to develop a BI incorporating all indicators for a more comprehensive assessment and understanding of bikeability in urban environments. One general limitation of this review is that in assessing bicycle infrastructure design principles in BIs, we considered if the BI considered at least one indicator for each bicycle design principle. Future studies should delve deeper, incorporating a broader range of variables to evaluate BIs effectiveness comprehensively.

Author Contributions: Conceptualization, T.A., A.P., D.J. and G.W.; methodology, T.A., A.P., D.J. and G.W.; software, T.A.; validation, A.P. and D.J.; formal analysis, T.A. and A.P.; investigation, T.A.; resources, T.A., A.P., D.J. and G.W.; data curation, T.A., A.P. and D.J.; writing—original draft preparation, T.A. and A.P.; writing—review and editing, T.A., A.P. and D.J.; visualization, T.A., A.P. and D.J.; supervision, A.P. and D.J. 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.

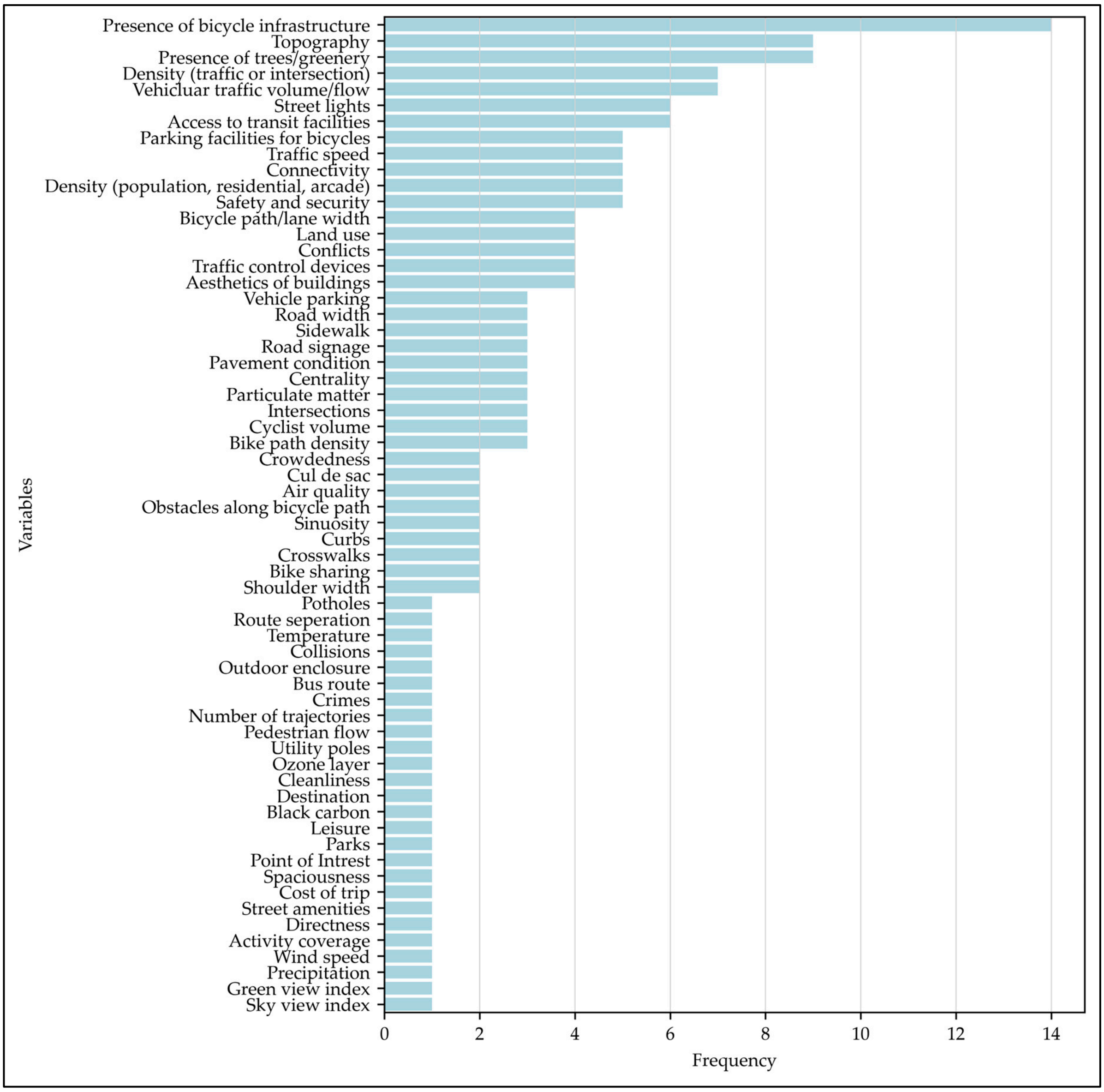
Informed Consent Statement: Not applicable.

Data Availability Statement: The datasets are available from the corresponding author upon request.

Acknowledgments: We thank the Higher Education Commission (HEC), Pakistan, for funding the Ph.D. research of Tufail Ahmed. We acknowledge Alam Zeb for helping with the PRISMA guidelines for the systematic literature review. We would also like to acknowledge the support and constructive feedback provided by Imran Nawaz.

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

Appendix A. Selected Indicators and Their Frequency in the Bis



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