Article

Designing a Cycling Dashboard as a Way of Communicating Local Sustainability

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Abstract: This paper conceptualizes the use of interactive urban dashboards in collecting and visualizing sustainability indicators at local scales through a cycling dashboard prototype for Münster. Urban dashboards are integrated platforms that bring various data types and sources together and automatize the visualization of information in real time. They can function as information hubs that work with mobile applications, sensor-based data, and crowdsourced platforms. Visualization of information can present both map-based data, text, and graphical information. In this study, a cycling dashboard is introduced that is developed as a prototype. The dashboard is based on the sustainability indicators related to cycling infrastructure defined by the German Sustainable Building Council (DGNB). It retrieves crowdsourced open data from Open Street Map (OSM) and automatically updates the information when new data are entered into the platform. This enables detailed exploration of the geo-referenced information up to street level and comparisons between different districts. In order to achieve a comprehensive framework, four main steps were included into the design and development process “determining a content by integrating future users, creating and evaluating a data inventory, designing the architecture of the dashboard, and implementing the prototype”. As a result, this study holistically draws a comprehensive framework for the urban cycling dashboard around three main modules focusing on the sustainability of cycling infrastructure “infrastructure guide, cyclists’ voice, and idea center”. Additionally, the first prototype of an open local cycling dashboard has been implemented. The prototype enables the automation of collection, analysis, visualisation, and deep exploration of sustainability-related data at local scales. The results of this study contribute to the status quo by supporting the design and development process of local urban dashboards through a participatory approach.

Keywords: cycling dashboard; urban cycling; sustainability; participation; user-centred design

1. Introduction

Cycling is considered a sustainable mode of transportation by nature. However, achieving a truly sustainable cycling infrastructure requires consideration of the complexity of a cycling network, its integration into the existing mobility system, and inclusive decision making and planning processes that involve various actors. In other words, transparency and strong communication in these processes become more prominent in order to enhance sustainability-aware actions in the local community and to realize local needs, priorities and public perception of sustainability for better planning practices [1–4]. An effective communication of sustainability information relies on the available data and functionalities of the communication platform. Available data on the cycling infrastructure are mostly quantitative and supported by traffic statistics based on sensor data (e.g., traffic counts, traffic accidents). However, in the last decade data sources are well supported by crowdsourced platforms such as Open Street Map (OSM) that enables precise spatial information voluntarily provided by local users. On the other hand, representing such large spatial data in an easy form that citizens can be well-informed, well-aware, and hence effectively
represented in the decision-making process remains a challenge due to the lack of technical tools and expertise [5–12].

Urban dashboards bear great potential to overcome these challenges by enabling automated data collection, analysis, and visualisation. They enable relevant data that are directly accessible to various groups in a comprehensible and interactive form, as well as in a user-friendly way, so that they can make confident decisions. Dashboards can vary greatly in terms of content and complexity, which on the one hand makes them flexible in use for knowledge generation and decision-making, but on the other hand requires a design that is appropriate for targeted groups and use cases. Mobility data play a central role in urban dashboards, but are usually represented by motorized traffic with non-motorized traffic for cyclists and pedestrians being ignored due to the lack of accessible and useful data. Therefore, there is an acute need for further research on challenges and obstacles in continuous data collection related to non-motorized mobility as well as its evaluation and final communication to the users through comprehensible data visualisation. The conceptual framework for a local urban cycling dashboard developed within this study, docks onto each of these challenges and provides a holistic design approach [2,3,13–15].

Within this context, the proposed framework is designed to support a better and more open understanding of local sustainability for cycling infrastructure through a local dashboard. It is developed on the case study of Münster, a location known as one of the cycling capitals of Germany. Based on findings from the existing literature and implementations, a prototype has been developed by focusing on the interactive visualization of sustainability indicators of cycling infrastructure (e.g., cycling network, quality and quantity of bicycle storage facilities) to evaluate the potential of the urban dashboards as a way of communicating local sustainability and the use of open data. The results provide a scalable and adjustable scheme for different local scenarios and different themes.

Following this introduction, this paper presents the related work. In the third chapter, we introduce the methodology implemented for the conceptual design of the dashboard and the design of the user study. We describe the results of the design and implementation steps in the fourth chapter. A comprehensive discussion is given in the fifth chapter. Lastly, a discussion of future insights and suggestions conclude the paper.

2. Related Work

Sustainability indicators of urban mobility infrastructure have been studied for decades and various cycling-specific indices have been introduced. At the local scale, many countries have evaluated the quality of cycling infrastructure within the scope of certification systems for neighborhoods and cities (e.g., [16–20]). These systems provide a comprehensive framework for the assessment of sustainability in several categories including the environmental, economic, and technical quality, as well as social inclusiveness. Nevertheless, there is a lack of transparency in the assessment process, which limits the exploration and understanding of the local sustainability at different granularity (e.g., district, neighborhood, and street levels) [5,21–23]. In the scope of certification systems, corresponding indicators are defined based on local conditions, long-term discussions, collaboration, and research. Indicators and weights are frequently reviewed and updated (e.g., [24]). In these documents, cycling-related indicators are usually included under the main category of non-motorized mobility and the common indicators aims to measure “accessibility, connectivity, safety, navigation, and services”. The assessment process is solely governed by professionals and the results are represented by sustainability labels (such as silver, bronze, gold, and platinum) [21,22,24–27].

Certification systems offer several environmental and financial benefits for urban development. On the other hand, the lack of transparency remains insufficient for supporting communities to grasp local conditions as well as to take necessary actions to achieve sustainable development. Openly communicating this information requires analytical tools and methods that facilitate collection, analysis, and interactive visualisation of spatiotemporal data. These tools and methods should provide automation in data processing to
overcome potential challenges resulting from a lack of expertise and resources [27–29]. Urban dashboards can serve this purpose as digital tools that can facilitate clear visualisation of complex spatiotemporal data. They vary based on the information desired to be communicated. In this scope, urban dashboards can support monitoring the performance indicators or diagnostic analysis focusing on a certain thematic information. They can be also used strategically for future predictions [13,30]. In the status quo, urban cycling is only addressed by single metrics in urban mobility dashboards (e.g., traffic counts as in Münster smart city dashboard [9], performance of bike-sharing systems in Dublin mobility dashboard [14], or bicycle observatory for Salzburg, Austria [2,15]). There are also a few geospatial tools in operation that aim to communicate sustainability of urban cycling with a holistic and user-centred approach. In this scope, ‘fix-my-city’ platform in Berlin transparently informs about recent developments of cycling infrastructure, depicts cycling accidents, and visualizes a user-centred happy-bike-index [31] ‘Bikemaps’ can globally be used for participatory mapping to collect user-centred data on actual and perceived cycling safety [32,33]. Despite the benefits of these tools, they can provide only a limited content that can corresponds to the sustainability performance of the cycling infrastructure. Furthermore, automated collection, analysis, and visualisation of large data required for a comprehensive approach remains a challenge. A diagnostic dashboard dedicated to cycling can help to overcome these challenges through more efficient data management, integration of different data sources, and can enable customized visualization of information through map-centered interfaces. Data retrieved from various data sources are regularly and automatically updated to support better understanding of the status quo, planning, and decision making. Diagnostic dashboards are usually more complex due to the detailed information that needs to be presented and require a user-centred design [13,30,34–36]. A user-centred design relies on understanding and reflecting users’ needs, priorities, and expertise in the design of the dashboard. The approach requires involvement of potential users from the first stages of the design process, which also helps to foster transparency, neutrality, and acceptance of the platform, as well as increasing the utility and usability of it [13,29,35,37,38]. In order to achieve inclusiveness, the design should offer a high level of interaction that assists and encourages exploration and action. Following this user-centred approach, the cyclists’ emotions and perceptions regarding the cycling infrastructure can also be reflected within the sustainability assessment [5,12,23,26,39]. Nonetheless, achieving this can be time-consuming and incur system overheads. In order to overcome these challenges, a diagnostic dashboard should effectively integrate the following components of a design process “the content, corresponding data, underlying technical architecture, and the user interface (UI)”, while taking the local conditions into consideration [2,6,13,29,35,40–42]. Based on the findings of the literature review, this paper contributes to the solution of existing challenges by providing a comprehensive framework for the initial design and implementation of an urban cycling dashboard.

3. Materials and Methods

The methodology was structured in four steps based on the components of a design process of a dashboard “the content, corresponding data, architecture, and the UI” [2,13,29,40,42]. The framework is conceptualised over the case study of Münster, one of the cycling capitals of Germany and home to approximately 500,000 bikes with extensive cycling infrastructure throughout the city.

Determining the content of the dashboard includes two main steps “review of the indicators and a user study”. The user study was conducted based on the review of local sustainability indicators for cycling infrastructure to understand the needs of local users, as well as prioritise and co-design the content of the dashboard. The content as the backbone of the dashboard defines (a) necessary data and data sources, (b) required architecture for data collection, storage, analysis, and visualization, and (c) the UI. Therefore, we subsequently evaluated available open data sources for cycling infrastructure related to Münster and
reviewed existing research and implementations regarding the dashboard architecture and the UI. Potential usage data collected through a prototype helps to update the content over time. Therefore, a methodological loop could continuously be triggered to respond to the needs and priorities of local users (Figure 1).

![Figure 1. Workflow followed in this paper.](image)

### 3.1. Determination of the Content

#### 3.1.1. Indicators

In the scope of defining the local sustainability indicators of cycling infrastructure, this study focuses on the local framework established by the German Sustainable Building Council (DGNB) for neighbourhoods and urban districts (DGNB Quartiere). DGNB Quartiere has been actively used in Germany and its hinterland since 2011. The overall system contains five main categories “ecological quality, economic quality, sociocultural and functional quality, technical quality, and process quality” [24]. Cycling-related indicators are given under the section of non-motorized mobility. The indicators are updated in 2020 including 20 detailed indicators linked to four main categories (Figure 2).

Within the guideline, each category is weighted according to its priority in the overall certification system and a score is specified to each indicator in order to assess the level of achievement [24]. In this paper, we only focus on the existing structure of the city. Therefore, we excluded the mobility elements category, because of its strong emphasis on the new urban extensions. In order to provide an easy to understand framework for the user survey, we needed to rephrase the rest of the criteria defined by the DGNB. Simplified categorisation was determined as follows according to the corresponding criteria:

- Prioritisation of cycling in the districts:
  - Accessibility and connectivity of cycling network
- Prioritisation of cycling on site:
  - Prioritization and direct connection of cycling on site
  - Quality measures for the integration of cyclists into the existing traffic system
- Degree of fulfillment of quantitative requirements:
  - Accessibility of parking facilities
- Quality and accessibility of cycling facilities and charging facilities
  - Quality of parking facilities
- Accessibility of charging stations
- Accessibility of repair stations
- Wayfinding systems:
  - Wayfinding and navigation

<table>
<thead>
<tr>
<th>Category</th>
<th>Criteria</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mobility elements</td>
<td>Mobility elements promoting bicycle/pedestrian traffic</td>
<td>Existence of an innovative mobility element</td>
</tr>
<tr>
<td></td>
<td>Prioritisation of cycling in the district</td>
<td>Direct access to bicycle lanes</td>
</tr>
<tr>
<td></td>
<td>Direct access to publicly accessible bicycle racks form at least 80% of the buildings</td>
<td>Direct connection to a first degree cycling path</td>
</tr>
<tr>
<td></td>
<td>Prioritisation of cycling on site</td>
<td>Direct connection to a first degree cycling path and existence of cycling lanes on site</td>
</tr>
<tr>
<td></td>
<td>Direct connection to a first degree cycling path and existence of visually separated cycling lanes on site</td>
<td>Direct connection to a first degree cycling path and existence of physically separated cycling lanes on site</td>
</tr>
<tr>
<td></td>
<td>Prioritisation of cycling on site</td>
<td>Direct connection to a first degree cycling path and existence of independent cycling lanes on site</td>
</tr>
<tr>
<td></td>
<td>Degree of fulfillment of quantitative requirements</td>
<td>Existence of one parking space per 250 m² of usable space or per 20 people</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Existence of one parking space per 125 m² of usable space or per 10 people</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Existence of one parking space per 50 m² of usable space or per 5 people</td>
</tr>
<tr>
<td>Quality of the parking facilities for bicycles</td>
<td>Quality and accessibility of cycling facilities</td>
<td>Availability of the protection at the bicycle parking facility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Availability of protection against vandalism at the bicycle parking facility</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Availability of weather protection at the bicycle parking facility (min. 80%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Availability of lighting in the parking facility (min. 80%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Availability of charging stations for e-bikes (min. 50%)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Integration of the charging stations in a roaming-capable billing system</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Accessible bicycle repair facility in ten minutes walking distance from 70% of the buildings on site</td>
</tr>
<tr>
<td>Signalisation systems for cycling</td>
<td>Wayfinding systems</td>
<td>Signalization system partially available (or available, but not according to FGSV standard)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Complete signalization system (in accordance with the FGSV standard or a comparable standard)</td>
</tr>
</tbody>
</table>

Figure 2. Categories, criteria, and indicators of sustainable cycling infrastructure according to the German Sustainable Building Council (DGNB) Quartiere, as a local sustainability certification system for Germany at the district level.

3.1.2. Design of the User Study

Dashboards can serve various stakeholders with different expectations and level of literacy [2,37]. In the scope of the conceptual framework of a cycling dashboard, this study focuses on two major target groups, cyclists and decision makers. Cyclists are represented by the citizens of Münster with cycling experience in the city, local non-governmental organisations, cycling clubs, and decision makers include the local municipality and the Smart City Department of Münster. The user study involves an online survey with the target groups to understand their motivations in using a cycling dashboard, as well as their expectations, needs, and priorities while using it.

The survey was designed with a set of single tasks that were phrased in a comprehensible and non-biased way. It is divided into three main sections “prioritisation, open suggestions, and motivation”. Participants also gave feedback about their cycling habits.

**Prioritisation:** In the scope of prioritisation, participants were asked to run a pair-wise comparison between the criteria of sustainable cycling infrastructure according to the simplified categories. The results enabled us to understand the default settings in visualization of the dashboard. The priorities for each category have been calculated with the analytical hierarchy process (AHP) which enables us to derive relative priorities for a set of options. AHP assigns a numerical weight to each pair according to the pair-wise comparison. The comparison has been made in an adjustable scale according the desired sensitivity. The score ‘one’ expresses equal importance between two criteria. For validating
each participant’s pairwise comparisons a consistency ratio is calculated, values lower than 0.1 indicate consistent personal judgements [43,44].

**Open suggestions:** The participants were also given the option to share their opinions and suggestions to gain deeper insights about the users’ expectations from a cycling dashboard. In order to derive meaningful and aggregated results from the suggestions, collective qualitative analysis was applied. The comments were classified according to “the intended purpose of use, content, UI design, and visualisation” [45,46].

**Motivation:** In the motivation section of the survey, participants graded three use case scenarios using a scale ranging from 0 to 100. Three use case scenarios involve “sharing information, receiving information, and exploring information to create knowledge”. The individual motivations ranging from 0 to 100 are aggregated with a robust median average separately for each user group. The resulting averages of usage motivations were visualised by opposing two triangle radar charts.

In addition to the user survey, semi-structured interviews were conducted with the Cycling Office, Smart City Department, and the Cycling Advocacy Club of Münster [40]. The analysis and visualisation of each stage were automated by using R programming language.

**Pre-testing and recruitment:** Pre-testing was conducted before the actual study in order to test and revise the design of the survey and the tasks. This stage included reviews and think aloud studies with seven participants. The approximate time for completing the survey was determined as 15 min based on the pre-testing. The actual study was conducted online between 24 November and 23 December 2021. Target groups were informed digitally and orally, and invitations were circulated through scientific institutions (University of Münster, Institute for Geoinformatics, Institute for Geography, Institute for Landscape Ecology, local student committee), local government (Mobilitätsplanung Stadt Münster, Fahrradbüro Stadt Münster, Smart City Stabstelle Stadt Münster, Wissenschaftsbüro Stadt Münster), as well as non-governmental organisations dedicated to cycling (Interessensgemeinschaft Fahrradstadt Münster e.V., VCD Regionalverband Münsterland e.V., ADFC Kreisverband Münsterland e.V.).

**Case study area:** Münster is located in North-Rhine Westphalia (NRW), Germany, with approximately 315,000 inhabitants [47]. It is nationally and also internationally known for its high share of cyclists in urban mobility. The share of cycling in mobility was calculated as 44% of all traveled paths in 2019 [47,48]. Therefore, the cycling infrastructure in the city needs to be maintained and continuously improved to meet the demand. Recently, initiatives have been formed to achieve a city-wide cycling network 2.0 with new cycling streets and routes aimed at providing user-friendly cycling infrastructure and an enhanced cycling experience [8,47,49,50]. In this framework, citizens are regularly integrated in the decision-making processes through user workshops [49] or route-tracking events and mapping surveys [8,50]. Although transparent communication with citizens and their participation in the decision-making process are highly important for the local authorities, current methods remain insufficient to inform citizens about the outcomes of their participation and to collaborate with broader public. There are also academic case studies for Münster that combine urban cycling and GIS such as participatory mapping for cycling routes, conflicts within urban cycling, and collaborative games for exploration of cycling infrastructure in the city [51–53]. However, in application, the only accessible cycling data that are openly communicated to citizens are the traffic counts for bicycles on the smart city dashboard of the city [9].

### 3.2. Data Sources

Focusing on the DGNB indicators for urban cycling, we created an inventory for open data portals (ODPs) available on the national, federal, and urban scales, as well as application programming interfaces (APIs) provided by mobile mobility services. The results of the study revealed that the open cycling data published on ODPs by the public institutions are insufficient to cover the relevant content (Table 1). The urban level ODP for Münster provides data on cycling infrastructure including traffic calmed streets, winter service of
cycling paths, as well as parking facilities around the main train station. Furthermore, the data available through ODPs mostly do not provide continuity and there is usually interoperability issues because of the different identifications used for the same data within the same dataset as a result of the absence of data standards. In the scope of this study, OSM provided better and detailed spatial data on cycling infrastructure, network, and facilities in Münster. Detailed methodology for the automated data extraction of cycling infrastructure from OSM can be found on the corresponding github repository \[54\]. However, as a crowdsourced platform, potential inconsistencies and incompleteness of the content can occur with the OSM data \[5,55\]. Nevertheless, our research on the ODPs revealed that only OSM presents a more complete dataset for the required indicators within the case study area.

### Table 1. Comparison of open data portals (ODPs) on cycling related data in Münster.

<table>
<thead>
<tr>
<th>Data Source</th>
<th>Link</th>
<th>Categories for Cycling Related Data</th>
<th>Traffic Stats</th>
</tr>
</thead>
<tbody>
<tr>
<td>ODP Münster (MS)</td>
<td><a href="http://opendata.stadt-muenster.de">opendata.stadt-muenster.de</a></td>
<td>On-Cycling</td>
<td>Network</td>
</tr>
<tr>
<td>ODP data NRW</td>
<td><a href="http://open.nrw">open.nrw</a></td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>ODP Germany</td>
<td><a href="http://www.govdata.de">www.govdata.de</a></td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>OSM</td>
<td><a href="http://openstreetmap.org">openstreetmap.org</a></td>
<td>+</td>
<td>+</td>
</tr>
</tbody>
</table>

\(a\) On-cycling infrastructure includes types of cycling paths/streets and further traffic adaptions. \(b\) Network includes the official cycling network and the wayfinding system. \(c\) Facilities include the amount and quality of repair and parking facilities. \(d\) Traffic statistics include traffic counts, tracked traffic volumes, and accidents.

### 3.3. Architecture

Based on the literature, a three-tier architecture that consists of data (data modelling and databases), method (automated and optional analyzes), and a presentation tier (graphical UI with interactive visualizations and mapping tools) provide a common framework for diagnostic dashboards. The suggested framework for the architecture of the cycling dashboard is based on the main functionalities suggested in the content, the review of the web applications \[31\], and the literature \[2,3,13,15\].

Design of the architecture for an urban dashboard should guarantee “scalability, interoperability, and portability”. Scalability is essential for achieving locally adaptable versions of a dashboard. It is also necessary for securing its adaptability to future improvements based on changing local conditions, the need for new functionalities, new data, and data sources \[2,13\]. Interoperability is necessary for handling heterogeneous data. Therefore, the definition of the content of the dashboard and required data is important to establish from the beginning \[2,13,15\]. Portability facilitates open access to data processed by the dashboard, either by providing an API for locally stored data or by linking to external data portals and APIs (e.g., OSM). It is very important to manage data coherently with the corresponding data protection regulations and ethical guidelines \[13\].

### 3.4. User Interface

The design of the UI elements of a dashboard mainly determines its performance in providing an effective, intuitive, and pleasant user experience. In the scope of analytical dashboards, design process of a UI includes (a) the general visual style of the interface, (b) a clear thematic structure to navigate through the dashboard’s content, and (c) the arrangement of single visual components on one screen \[2,13,29,30,37\].

Visualisation of aggregated data in an abstract way is essential to enable users to easily understand the represented information. A map-centered UI supported with graphical and textual information provides an effective solution for abstract representation of large georeferenced data as in an urban dashboard \[42\]. In the scope of analytical dashboards, interactive visualisation of information is essential in order to encourage exploration in different granularity such as street, district, and urban levels \[29,30,56,57\].
4. Results

The user study was conducted with 125 participants consisting of 117 citizens and 8 decision makers. All participants completed the user survey, however, two sets of individual priorities were excluded due to inconsistency in the prioritisation results. We received suggestions and feedback related to the use case, content, and the design from 42 citizens and 2 decision makers. The user study reached participants from every age group. Of the participants, 79% stated that they use their bike everyday for daily commute (Figure 3).

![Figure 3. (a) Aggregated results of cycling frequency of the user study participants. (b) Age distribution of the participants.](image)

The prioritisation of the sustainability criteria revealed that:

- Both target groups assign the highest importance to measures for integrating cycling into the existing traffic system. On the other hand, citizens are more concerned about the cycling on site whereas decision makers are more interested in the district level cycling network. The less important category for both target groups was found to be ‘quality of parking facilities’ and “wayfinding and navigation”.
- For decision makers, providing sufficient parking space is nearly as important as implementing measures for cycling priority on site.
- Cyclists did not prioritise having sufficient parking facilities as much as local decision makers.

The user survey enabled participants to optionally give open suggestions about the content and design of the dashboard. The suggestions involved feedback in four main categories:

- Reporting and receiving information about future plans and proposals
- Reporting and receiving information about the current status of constructions
- Mapping insufficient and damaged infrastructure
- Mapping perception of safety and safety risks.

The results of the user study revealed that the main motivation of citizens and decision makers in using a dashboard is receiving information more than generating and sharing data. On the other hand, citizens also showed interest in having the ability to collaboratively map and manipulate data, as well as comment on certain information (Figure 4). Setting up a profile based on the defined roles such as decision makers and cyclists was also mentioned by the participants to personalize the content (e.g., emphasis on the favorite district). Based on these results, we focused on the visualisation of physical indicators of cycling infrastructure in the design of the dashboard; however, we also suggested optional modules that will enable the use of the dashboard as a participatory platform.
Integrating participatory modules into the dashboard increases the complexity in the content and use. In this scope, different expectations on the dashboard must be respected within its design. As a result, we suggested four main modules for the dashboard that integrates the necessary functionalities “landing page-dashboard info, infrastructure guide, cyclists voice, and idea center”.

The first module ‘dashboard info’ provides an introduction page. Within this page the users can find the explanation for the modular design as well as the latest content per module. Availability of the additional links for the external data sources (e.g., OSM), open source code for the dashboard, as well as transparent information on the design and conceptualization process are supported by the first module. With this modular approach, we aim to increase the transparency, interoperability, and reproducability of the dashboard for future improvements and integration. Eventually, the data protection measures and the conditions of data management are specified here as well. The second module is a core module called ‘infrastructure guide’. This module contains a base map which presents the existing cycling infrastructure based on the spatial data retrieved from OSM and frequent collection and analysis of data for the sustainability indicators. The third module is a secondary core module called ‘cyclists’ voice’. The aim of this module is to collect and communicate information for infrastructural deficiencies and user perceptions. Two functionalities were suggested to achieve this aim, deficiency mapper which enables cyclists to map current deficiencies and cycling emotions mapper which users can use to communicate their perceptions of sustainability for the cycling infrastructure through mapping emotions. Temporal aspect is particularly important for this module, therefore, the collected data should contain date and time information. Sharing textual information or images can be integrated optionally to the shared information to gain deeper understanding of the user perceptions of sustainability. The analysis of the text data can be automated in the backend of the dashboard to receive aggregated results including the frequency analysis and word clouds. The last module is called ‘idea center’. It is designed as a platform for enabling decision makers to map future cycling-related projects with detailed information such as timeline, location, goals, and responsible authority. This module allows decision makers to involve citizens in the decision-making process from the conceptual design of a plan. This requires early communication of decisions to citizens and responding to their needs and priorities in the decision-making process for achieving a collective solution. This aim can be achieved within this module by means of communication such as online surveys.

The suggested architecture offers scalability, interoperability, and portability. Coherent with the architecture, a high-level UI design is conceptualised in a modular structure including a separate page for each module and a fixed navigation bar on top. For the landing page, the initial view contains different panes for each module. A button represented with
a person image on the top-right corner directs the user to the login page and registration. However, it is only for further personalisation of the usage of the dashboard. Therefore, a personal account does not affect the general function or the utility of the service. However, when integrating personal accounts for participatory mapping modules a clear plan for geodata management is required determining usage rights and ensuring data privacy and security [15]. These data protection measurements are given in a visible manner to secure the accessibility of required information. This information should be supported with external links, thus allowing users to reach it at a different granularity. Scrolling down on the landing page leads to the remaining information (Figure 5).

Figure 5. Multi-modal layout concept for the web-based UI design.

Regarding the design of the UI for the core modules, our conceptual framework suggests a map-centered interface for participation and data visualization. The second module ‘infrastructure guide’ visualizes the status of cycling infrastructure based on crowdsourced open data on the OSM. On this module, the users can explore spatiotemporal information related to the sustainability indicators for cycling infrastructure at different scales such as a street or a district through toggling different layers on and off and clicking on the spatial objects such as districts, cycling lanes, parking spaces, and repair facilities. On the interactive map each object contains a pop-up information box containing textual and graphical information related to the properties of each cycling elements. Users are also able to compare different parts of the city according to the quality and quantity measures. This module also corresponds to the common application of urban dashboards (Figure 5).

The third module ‘cyclists’ voice’ combines participation and data visualization of user-generated data. On this module, users are enabled to map the location of deficiency report. Therefore, they can either draw lines or point geometries, that are directly snapped to a corresponding underlying cycling infrastructure (e.g., parking facility or separated cycle lane). After the users’ confirmation of the automated spatial snapping, they fill a form asking for the required attributes (the category of the deficiency, corresponding emotions,
textual description, and optionally an image). The resulting spatial objects can be filtered by their attributes such as time, location, or the frequency of reported cases (Figure 5).

The fourth module 'the idea center' focuses on the visualization of projects and plans related to the cycling infrastructure. These objects can be filtered by time and location and distinct objects can be selected regarding the corresponding status in time. Within this module, the participation mode is not available by default, but must be enabled by the decision makers for each plan (Figure 5).

In the scope of the three-tier architecture, data tier facilitates the data deployment from different sources and allows the local storage of user-generated data. Methods tier enables efficient analysis of the results and performs an automated assessment of indicators. The presentation tier includes the frontend design of the dashboard. It involves the interactive communication and visualization of information. In terms of our conceptual framework, the presentation tier secures easy representation of different modules of the dashboard and presentation of aggregated information (Figure 6).

![Figure 6. Framework for the three-tier architecture.](image)

**Prototypical Implementation of the Cycling Dashboard**

In the scope of this paper, we implemented a prototype of the cycling dashboard for Münster [58]. Based on the available data and common practices, we focused on the second module the 'infrastructure guide'. As a landing page, we locally integrated the module into the existing Smart City Dashboard of Münster which is developed and governed by the Re:edu [9] (Figure 7).

The prototype visualises data related to the sustainability indicators for cycling infrastructure. The data and the default visualisation are designed based on the priorities of local users which are determined as the cycling priority and sufficient parking facilities. Indicators related to the priority of cycling in the district and on site contains cycling network, its integration to the high level of transportation system, and road type coverage (e.g., separate or on road bike lanes). The sufficiency of the parking spaces that is linked to the degree of quantitative requirements is represented by the quantitative and qualitative measures of the parking facilities throughout the city. The required data are retrieved from
OSM and the dashboard automatically updates information when new data are entered into the platform (Figure 8).

Figure 7. Local landing page integrated into the existing Smart City Dashboard (in German). Modified reproduction with permission from Lorenz Beck, Local cycling dashboard prototype for Münster; 2022 [59].

Figure 8. Default visualisation focusing on the cycling priority and quantitative requirements for bicycle parking. Reproduced with permission from Lorenz Beck, Local cycling dashboard prototype for Münster; 2022 [59].

The UI allows users to interact with the individual objects of cycling infrastructure at different spatial granularity as well as to compare aggregated information at district level. Meanwhile, non-linear objects such as parking areas or bicycle shops, form clusters at coarse levels. Users are able to zoom up to street level detail and click on the desired object such as a parking place or on a path to explore more details including information on the type and pavement of the cycling lanes, capacity and the quality (weather and theft protected) of the parking spaces, or the tool equipment at a repair station (Figure 9). Additionally, the district view can be activated on the left pane. At the district level, the
users are able to view graphical representations of aggregated information on the parking spaces, cycling network, and repair facilities. Users can also compare different districts in the city and explore differences (Figure 9).

Figure 9. Interactions on street level (left) and district level (right). Reproduced with permission from Lorenz Beck, Local cycling dashboard prototype for Münster; 2022 [59].

The architecture allows additions for participatory modules in future versions of the local cycling dashboard for Münster. Focusing on the infrastructural information, the first prototype provided a groundwork for automated data collection, analysis, and visualisation according to the local context and based on the framework provided by the DGNB. Despite the limitations on the available and interoperable data sources, the prototype presents an integrated and open platform that brings digital services together from separate web sources (including OSM and [9]).

5. Discussion

The proposed framework was developed following a comprehensive and inclusive process and provides a local framework for Münster. Some components of the conceptual framework of the cycling dashboard such as the modular design, definition of criteria and indicators, the initial design process itself, as well as the methodology of the user study can be transferred into future implementations. However, other components such as the three-tier architecture and the UI design should meet local prerequisites such as integration into the municipality’s geodata infrastructure or corporate interface design [30]. Additionally, it should be emphasised that the priorities of the criteria and indicators are contextual only for Münster and are expected to differ in other local contexts [5,60]. During this study, we observed this discourse through differences between the priorities defined by the DGNB and our sample group [40]. This highlights the importance of integrating the local community’s perception into the design of a local dashboard and a local evaluation of sustainability for cycling infrastructure [5,12,23,26,39]. The user study conducted in the scope of this paper can be seen as a blueprint for the initial design process of a local urban cycling dashboard.

The prototype provides a useful tool for decision makers, citizens, researchers, and service providers. Decision makers can benefit from the proposed cycling dashboard to understand the local needs and conditions better and therefore, to provide more responsive plans in the future. Citizens can use the dashboard to decide on their route, to explore and compare different districts to decide on an area to live or explore cycling as a sustainable mode of transportation alternative to cars, and to explore the connectivity of the cycling network with the general mobility system in the city. The suggested framework enables researchers and service providers to add additional modules based on different scenarios.
Besides the benefits of the exemplary use case scenarios, the suggested framework bears the following limitations.

Coverage of the user study: As the user study only defines two user groups—cyclists and decision makers—it bears the following limitations. This does not reflect the broad audience that an urban dashboard can eventually reach as it omits other types of users such as researchers, journalists, or service providers [37]. Additionally, the user study mainly represents young and active cyclists as the respondents of the user survey. We consider this as a natural bias, as high-frequency cyclists are more interested in this research and younger individuals constitute the largest group of cyclists in the city [48]. The decision makers were represented by eight participants. Although this number reflects the needs and priorities of the related local authority, the number is not large enough to fully represent this target group. The feedback related to the user survey revealed that participants had difficulties during the prioritisation task because it rapidly felt repetitive. In order to overcome these challenges, we suggest focus group meetings and user workshops during the conceptualization process. This could help to create more robust use case scenarios and personas that can accurately depict potential users and use cases [37,41].

Interoperability of data sources: Dashboards are commonly used as an information hub of consolidation and communicating different kinds of spatiotemporal data from various sources (e.g., sensor-based, participatory surveys, or infrastructure data) [2,15,29]. However, our approaches rely solely on OSM data to represent the cycling infrastructure, even though related data can be found in ODPs of the federal state and the city. This is mainly due to the lack of data standards and the need for additional, time-consuming data conversions required to achieve interoperability between different data sources. However, the use of OSM data also brings challenges of its own such as incompleteness of data, inconsistencies within attributes and time-consuming data preprocessing [5,33,38,55].

Sustainability assessment of cycling: The proposed indicators for measuring sustainability are merely conceptual. Further review and research are needed to adapt or develop concrete methodologies that can turn the relevant data on cycling infrastructure into operationally measurable indicators [5,22]. The identified need to also respect user-centred data such as safety perceptions that can be collected via participatory mapping tools [31,33] could bring more temporal insights into the urban cycling dashboard. However, integration of participatory data into the automated calculation of sustainability indicators requires deeper investigations of the relations between cycling emotions, perceptions, and infrastructure [5,12,39].

6. Conclusions

In this paper, we proposed a conceptual framework for the design and implementation of a cycling dashboard for Münster, Germany. The suggested framework provides a guideline for future development of analytical dashboards aiming to automate data collection, analysis, and visualisation with a strong focus on a certain theme. The results of this study revealed that the needs and priorities regarding the sustainability indicators and the usage of an urban dashboard differ between different stakeholders and according to the local context. Automation of sustainability assessment and its effective representation through interactive visualisation yields better understanding of deficiencies and bottlenecks in achieving urban sustainability. This can be strengthened by participatory modules that allow users to go beyond exploration and be part of the local sustainable development. Claiming a user-centered approach, the proposed framework facilitates deep exploration of local sustainability measures and allows collaboration between various stakeholders aiming to promote more local-aware decision-making processes for sustainable urban planning and design, in addition to sustainability-aware actions among citizens.

To respond to the different needs and priorities of users, a three-tier architecture and modular UI provide an effective solution for the development of an urban cycling dashboard. This approach also enables scalability and adaptability to different use case scenarios and local contexts. Therefore, it allows not only continuous monitoring of the
local status of sustainability, but also facilitates comparisons between different cities in terms of local priorities, deficiencies, and motivations. Additionally, the implemented dashboard prototype automatically extracts and preprocesses data from OSM and allows users to deeply explore cycling infrastructure categorized by the selected sustainability indicators and to compare aggregated information on a district level.

Usability of multiple data sources presented the biggest challenge for accurate and comprehensive representation of information. For future studies, interoperability issues among various data sources should be examined further for better practices. The user-centred approach should be maintained after the implementation of a local urban dashboard in order to guarantee and improve its usability, locality, and responsiveness. From a long-term perspective, the effectiveness of the urban dashboard should be assessed on its impact on sustainable urban planning in Münster.

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