Master Thesis

Master Program in Geospatial Technologies

Guidelines for a participatory urban cycling dashboard: A case study for Münster, Germany

Author: Lorenz Beck

Institute for Geoinformatics (ifgi) University of Münster

Supervisor: Dr. Simge Özdal Oktay (ifgi)
1st Co-supervisor: Dr. Carlos Granell Canut (GEOTEC, UJI Castellón)
2nd Co-supervisor: Prof. Dr. Christian Kray (ifgi)

February 2022

Contents

Figures

Tables

Abbreviations

AHP	Analytic hierarchy process
API	Application programming interface
BLOS	Bicycle level of service
CC	Citizens and cyclists
DGNB	Deutsche Gesellschaft für nachhaltiges Bauen
DM	Decision makers
GIS	Geographic information system
GIScience	Geographic information science
GPS	Global positioning system
OSM	OpenStreetMap
RQ	Research question

Abstract

Urban cycling as a sustainable mobility system gets increasing attention in practical and academic urban transportation planning. At the same time, many cities are willing to foster their transparency and openness of urban data by utilizing urban dashboards. In conjunction, it lacks digital tools such as an urban cycling dashboard that have the potential of collecting cycling-related data, assessing it, and finally communicating its information with data visualizations. However, intended users are rarely integrated already at the earliest conceptualization stage of such an urban dashboard, which often results in low usability and utility. Simultaneously, there is a lack of integrating cyclists and their experiences into the quality assessments of urban cycling. To address these practical and research problems, this work aims in conceptualizing a user-centered and participatory urban cycling dashboard. Therefore, we conduct a user survey with cyclists/citizens, and decision makers from our case study in Münster, Germany, and apply findings from literature and dashboard reviews. The results show the users' preference for an informational focus on cycling infrastructure but also their motivation of exchanging information on cycling experiences and future projects. Generally, the feedback for integrating the local users at earliest stage is positive. Such a user-centric conceptualization is a first systematic step of developing a participatory urban cycling dashboard that should support the understanding of a complex urban cycling system as well as fostering more participation and transparency in urban cycling planning.

Keywords: Urban dashboards, user-centric design, sustainable cycling, indicators and assessment, participation

1 Introduction

Sustainable urban mobility is considered to hold important transformative power towards more sustainable communities (WBGU 2016). Sustainable urban mobility is characterized by the linkage of environmental responsibility, social justice, and economic viability (Rau and Scheiner 2020), and by fostering an accessible city with close and well-connected places, based on diverse, car-free, and also smart modes of transportation (DGNB 2020; WBGU 2016). Besides public transport, and walking, cycling is considered to be probably the most sustainable mobility mode in cities (BMVI 2021; Pucher and Buehler 2017; Soliz 2021; UBA 2021). However, despite generally rising numbers of cyclists (Pucher and Buehler 2017) a sustainability of the urban cycling system itself is still often not guaranteed (Psarikidou et al. 2020; Soliz 2021).

Simultaneously, an increasing and networked use of technology and data are often considered as important drivers of sustainable mobility in cities (Estevez et al. 2021; Karduni et al. 2017; WBGU 2016), which also promises safer, more efficient and more attractive urban cycling (Behrendt 2020; Nikolaeva et al. 2019; Oliveira et al. 2021). Besides current trends on smart cycling that utilize networks of smart infrastructures and bicycles (Nikolaeva et al. 2019; Rau and Scheiner 2020) there is the general rise of collecting cycling-related data aiming at a deeper understanding and better decisions on the urban cycling system (Nelson et al. 2021; Werner and Loidl 2021). Despite the improved openness of general urban data, citizens still can hardly understand its information or comprehend resulting decisions. Here, necessities of a smart city or government are to ensure a fair, open, participative, and comprehensible use of technological innovations and its data (Estevez et al. 2021; Kitchin and McArdle 2017; WBGU 2016).

Our study is contextualized within these two practical problems of missing sustainability in urban cycling as a system and the lack of digital and user-centric tools for urban stakeholders to turn societal value out of urban data. In this overlap we aim at conceptualizing a participatory urban cycling dashboard that focuses on collecting, assessing, and visualizing urban cycling data to support a better understanding of the complex cycling system and foster more participation and transparency in urban cycling planning. To ensure the later utility and usability of an urban cycling dashboard we integrate the future local users into this earliest stage of the conceptualization. Therefore, we conduct a user survey with citizens and cyclists as well as decision makers from our case study in Münster, Germany, and refine its findings with insights from literature and dashboard reviews.

Throughout our work we will follow these two research questions (RQ):

> RQ1: What are the users' motivations to receive information from and to participate to an urban cycling dashboard?

RQ2: How should an urban cycling dashboard be conceptualized supporting participation and transparency in sustainable urban cycling?

The intended audience of our work are researchers as much as practitioners from interdisciplinary fields such as geographical information science (GIScience)/ systems (GIS) as well as sustainable urban transportation planning and human computer interaction. By further connecting these research fields we aim at expanding the knowledge on the use of urban dashboards in the field of cycling, as well as guiding the design and development for practical implementations of local urban cycling dashboards.

2 Background

As our research lays in the overlap of rapidly evolving and interdisciplinary fields of GIScience, and sustainable urban transportation planning (Rau and Scheiner 2020), as well as in human computer interaction, a well-organized and informative background section is crucial. Therefore, the goals of this background section are 1) to substantiate the selection of the research problem and its corresponding RQs, 2) to create a common base of theoretical knowledge including the clarification of terminology, 3) to contextualize our research within existing literature, 4) and to lead over to an appropriate choice of methods (Rowley and Slack 2004).

The following subchapters will address 1) key concepts of urban cycling and its sustainability, 2) the use of spatial data for urban cycling, 3) urban dashboards and cycling, as well as 4) an introduction to cycling in Münster.

2.1 Key concepts of urban cycling and its sustainability

Using the term cycling we mean its various forms of actively riding bicycles, cargo bikes, or electric bikes (BMVI 2021). While using the term urban cycling, we do not only imply this mere act of cycling in a city, but rather refer to urban cycling as a system. This urban cycling system is built upon the composition of policies and planning, the physical infrastructure, and the perceived cycling experiences (Hull and O'Holleran 2014; Kazemzadeh et al. 2020), and includes a field of various actors, that we refer to as the stakeholders. These stakeholders are cyclists, cycling advocacies, non-governmental organizations, municipal politicians, and urban planners (Brocza and Kollarits 2020). Here the stakeholder group of the cycling community is built upon a very heterogenous group of individual cyclists (Brocza and Kollarits 2020; Fernández-Heredia et al. 2014; Marquart et al. 2020). We will subsequently often use the term of decision makers that implies both politicians and planners in the context of administrative governance. Here, politicians mean to elaborate bigger mobility strategies for cities and making direct decisions in form of policies, while planners (especially spatial planners) rather work instrumentally on specific implementations of these strategies (Hull and O'Holleran 2014).

2.1.1 Cycling for urban sustainability

Cycling in the city combines environmental, social, and economic benefits that together support sustainable communities (Pucher and Buehler 2017). Due to transporting with zero-emissions cycling is climate friendly, prevents pollution, and therefore results in a better air quality and less noise (Heinen et al. 2010; Marquart et al. 2020; UBA 2021; WBGU 2016). Together with cycling as a space-saving type of mobility, this creates a higher quality of stay in the public and holds potential to revive urban spaces (BMVI 2021; DGNB 2020; Pucher and Buehler 2017). Respecting the social side of cycling, it can improve the personal and public health due to physical activity or recovery of stress, and fostering greater social interactions in the traffic space (DGNB 2020; Heinen et al. 2010; Latham and Wood 2015; Pánek and Benediktsson 2017). Additionally, it can reduce urban inequities by creating a more accessible city integrating a wider range of the community (DGNB 2020; Psarikidou et al. 2020; Schröder 2021; Soliz 2021). Not to mention that cycling can be the fastest mode of transport in cities (Heinen et al. 2010; Marquart et al. 2020; Pucher and Buehler 2017). Furthermore, cycling can save personal money (Marquart et al. 2020) and is economically beneficial for municipalities as its infrastructure is cheaper and new investments will pay back more than its costs (Heinen et al. 2010; Kazemzadeh et al. 2020).

Challenges of cycling in cities

However, there is the legitimate question that if cycling provides so many sustainable advantages for a city, then why is not everybody cycling (Psarikidou et al. 2020)? Of course, cycling in cities also face some inherent challenges, as higher physical vulnerability, carrying loads, being exposed to the weather, the need of more physical movement, or remaining financial costs (Heinen et al. 2010; Hull and O'Holleran 2014; Manton et al. 2016; Pajarito and Gould 2018). But besides these personal hurdles, a city's general bikeability, its cycling-friendly decision-making, and a cycling-positive atmosphere in the local community plays a major role in minimizing structural frictions and getting people cycling (Marquart et al. 2020; Pajarito 2018). Here, an integrated policy approach is most efficient including bicycle promotion, awareness building, or education and skill training just as much as spatial planning of the local cycling infrastructure (BMVI 2021; Heinen et al. 2010; Hull and O'Holleran 2014; Schröder 2021).

Spatial planning of urban cycling

In general urban transportation planning cycling has long been neglected as a legitimated mean of transport or has just been perceived as an infrastructural add-on to automobility (Hull and O'Holleran 2014; Pánek and Benediktsson 2017; Psarikidou et al. 2020). But Hull and O'Holleran (2014) emphasize the importance of spatial planning and government policies to create attractive, safe, and comfortable cycling (Marquart et al. 2020). Here, approaches of cycling policies and planning can be really diverse and complex, including the different stakeholders that participate from non-governmental bottom-up approaches to traditional top-down governances (Psarikidou et al. 2020).

Fortunately, the awareness of cycling has changed in the recent decades, what is noticeable not only by rising numbers of related publications in interdisciplinary research fields (Pucher and Buehler 2017), but also by increased respect to cycling as a form of urban mobility in policy and planning practices (BMVI 2021; Marquart et al. 2020). As a result, nowadays there are wide and interconnected networks consisting of cyclists, cycling advocacies, governances, and non-governmental organizations to exchange knowledge mainly about best practices of cycling infrastructure (Pucher and Buehler 2017). The tangible outcome of this cycling-positive development are increasing numbers of cyclists in cities all over the world, regardless of whether cycling is already an adapted form of urban mobility (e.g. Amsterdam, Netherlands, or Copenhagen, Denmark), or new and innovative (e.g. Bogotá, Colombia, or Portland, USA) (Pucher and Buehler 2017).

2.1.2 Sustainable urban cycling

As mentioned in the previous subsection, cycling in the meaning of actively riding a bicycle, can be obviously beneficial for an individual and can clearly contribute to a more sustainable city in several ways. Therefore, one might justly ask the questions what we mean by mentioning sustainable urban cycling or how urban cycling can be actually not sustainable? Here, the term of sustainable urban cycling does not really suit to the mere act of cycling in a city but rather fits to cycling as a system of urban mobility. As in a generalized perspective the numbers of cyclists are rising in cities all over the world (Pucher and Buehler 2017), that does not imply that these cities and their urban cycling systems automatically become more sustainable. One simple example here is that a mere rise of cyclists and no infrastructural adaptions might exceed the capacity of a cycling infrastructure and therefore cause conflicts between cyclists themselves or other traffic participants as car drivers or pedestrians (Marquart et al. 2020).

The social within urban cycling

Psarikidou et al. (2020) point out the importance of the social in an urban cycling system to really turn it into a form of sustainable mobility. They argue that research studies should not only work on how urban cycling can potentially contribute to a more sustainable city in future but focusing on the sustainability of urban cycling as a form of mobility itself including its possible unsustainabilities (Psarikidou et al. 2020). Here, cycling inequalities or inaccessibility occurs when new investments, developments, or even maintenance of cycling infrastructure happens not equally distributed within a complete city but favoring areas of particular social groups (Soliz 2021). Of course, sustainable outcomes still might prevail to most individuals of a city's community but that does not mean that it is sustainable in general. Remaining deficits in cycling infrastructure might in turn even marginalize or disadvantage certain urban groups if they are not respected well enough in the decision-making (Soliz 2021).

The importance of a local community's cycling experience

Soliz (2021) points out the important role of the local cycling community itself to foster socially fair urban cycling. It is common critique that decisions on urban cycling are mainly made as top-down processes and based on formal infrastructural manuals or guidelines (Barrero and Rodriguez-Valencia 2021; Marquart et al. 2020; Soliz 2021). This neglection of the cycling community is also evident as Barrero and Rodriguez-Valencia (2021) show in their review that only two out of 48 cycling infrastructural guidelines and manuals include cyclists' participation and respect their cycling experiences.

Cycling experiences, or also referred to as cycling perceptions or emotions, are crucial for cyclists as they strongly perceive their direct surrounding including not only the cycling infrastructure, but also interactions with other traffic participants, or the natural or built environment (Liu et al. 2021). This importance of subjective cycling experiences also becomes evident as cyclists are even willing to ride detours through more appealing minor residential roads or green natural environments, rather than cycling along a major car road with appropriate cycling infrastructure (Marquart et al. 2020; Pánek and Benediktsson 2017; Snizek et al. 2013). A more detailed contextualization of cycling infrastructure and cycling emotions within the concept of cycling experiences is presented in the result subchapter 4.1 (p. 31-33) as findings from our first methodological literature review.

To integrate the cyclists' experience into the planning process is promising as it tailors the cycling infrastructure to the local cyclists' needs and preferences (Barrero and Rodriguez-Valencia 2021; Manton et al. 2016; Milakis and Athanasopoulos 2014; Pánek and Benediktsson 2017; Snizek et al. 2013). Here, Marquart et al. (2020) also highlight that the cyclists' experiences are not only supplementary information for decision makers but are necessary to respect as there is an existing gap in the perception of cycling quality between them and the cyclists. Here, decision makers often underestimate the role of emotions and experiences and therefore can easily miss the cyclists' needs and desires (Marquart et al. 2020; Milakis and Athanasopoulos 2014).

However, single cycling experiences have different importance depending on their locality. A comparison of participative studies in different places as Athens, Greece (Milakis and Athanasopoulos 2014), Reykjavík, Iceland (Marquart et al. 2020; Pánek and Benediktsson 2017), or Leipzig, Germany (Marquart et al. 2020; Pánek and Benediktsson 2017) shows contrasting differences in what the local cycling community perceives as good-experience cycling. While the natural environment and access to urban parks are minor points for cyclists in Athens (Milakis and Athanasopoulos 2014), in Leipzig and Reykjavík the natural environment plays a major and positive role for urban cycling (Marquart et al. 2020; Pánek and Benediktsson 2017). Milakis and Athanasopoulos (2014) already mention that their results have both, concordances, and discordances with the findings of other studies. Here, they point out the influence of the city's spatial context such as Athens as a metropolitan area (Milakis and Athanasopoulos 2014).

This section 2.1.2 (p.10-11) points out a need for a critical assessment of the sustainability of cycling itself. Therefore, an urban cycling dashboard should focus on providing a spatially complete but differentiated picture of cycling within one city and integrate the local cycling community and their cycling experiences.

2.2. The use of spatial data for urban cycling

Sustainable urban cycling should ensure accessible, short, timely, safe, and comfortable cycling (DGNB 2020; Hull and O'Holleran 2014). For achieving such a high-quality urban cycling, a proper understanding of its current status is necessary. Therefore, there is the need for available and meaningful information on urban cycling for both, decision makers but also for citizens and cyclists to decide on maintenance, future investments, or developments of cycling infrastructure (Hull and O'Holleran 2014; Pucher and Buehler 2017; Werner and Loidl 2021). Here, valuable insights can be derived from various types of methodologies and data, ranging from qualitative mobility behavior studies (Stadt Münster 2020a), ride-along interviews, or travel diaries (Liu et al. 2021) to statistical data on passing cyclists, cycling accidents (Nelson et al. 2015) or traditional spatial data on cycling infrastructure (Ferster et al. 2020). However, as our work is located within the fields of GIScience and GIS we will focus on georeferenced spatial data. Here, an urban cycling dashboard can not only work as a communication technology by interactively visualizing this information but can also contribute by collecting or assessing geospatial data related to cycling (Brocza and Kollarits 2020). Therefore, this subchapter 2.2 (p. 12-18) outlines 1) available geospatial data for urban cycling, 2) ways of participatively collecting data from cyclists about their cycling experiences, and 3) methodologies for assessing the quality or sustainability of urban cycling. 4) A final excursus is given regarding the trend of smartification of cycling, leading on to the following background subchapter 2.3 (p. 19-22) that outlines the urban cycling dashboard as a smart solution.

2.2.1 Variety of spatial data for cycling

A variety of spatial data can serve the assessment and future planning of urban cycling. On one hand, official data on traffic volumes of cyclists or on cycling infrastructure is often hold by municipalities. Here, punctual statistics as the number of passing cyclists (Smart City Münster 2021a) or traffic accidents including cyclists (Manton et al. 2016; Nelson et al. 2015) can give first spatial insights into urban cycling. While this data is often provided with temporal continuity, it cannot provide a spatial complete picture of traffic flows or volumes (Nelson et al. 2021). Furthermore, many municipalities also have infrastructural inventories with data on physical components of their cycling infrastructure (Ferster et al. 2020). While these follow internal quality standards such as a common categorization of cycling lanes, they cannot guarantee actuality or even the completeness of objects (e.g. parking racks) (Ferster et al. 2020).

On the other hand, crowdsourced data and volunteered geographic information (VGI) is often used in research as well as in practice as a potential source for cycling-related data (Kessler 2011; Nelson et al. 2021). This also goes in accordance with the previously defined need of increased cyclists' integration in urban cycling planning. In general, Kessler (2011) points out that cyclists have a natural enthusiasm of collecting and sharing information and knowledge to the cycling community. Using cyclists to collect data can happen in many various ways. Geospatial technologies such as global positioning systems (GPS) facilitate cyclists to generate georeferenced data as most crowdsourced data on cycling traffic volumes or flows is based on tracked trips (Nelson et al. 2021). However, cycling data from commercial applications (e.g. strava, komoot) can only be used by decision makers in a limited way, as their applications are focused on recreational performance and competition rather than depicting daily cycling commutes (Nelson et al. 2021; Pajarito 2018). Therefore, in research but also in practical urban transportation planning applications based on GPS are utilized to crowdsource cycling trip data from the cyclists directly but mostly within specific events (Pajarito and Gould 2018; Pajarito and Maas 2018; Smart City Münster 2021b). However, some research projects additionally turn the cyclists in a living sensor and extends the trip trajectories with georeferenced measurements on their urban environmental exposures (e.g. air quality) (Ueberham et al. 2019). Furthermore, also cycling-related social media posts that often contain a spatial reference can be crowdsourced and used as an alternative data source (Nelson et al. 2021).

Besides utilizing mobile applications based on GPS, cyclists can also actively map VGI via online and map-based platforms (Nelson et al. 2021, 2015). Here, the most known example is OpenStreetMap (OSM) or its cycling-dedicated release of CyclOSM, where the community cannot only contribute by mapping data on cycling infrastructure but also access all data due to its open data policy (CyclOSM 2021; Nelson et al. 2021). However, often challenges of consistency in data quality appear here (Ferster et al. 2020; Nelson et al. 2021). Besides generating spatial data on cycling infrastructural components, cyclists can also map their subjective cycling experiences that go beyond infrastructural experiences but respecting cycling emotions such as perceptions on safety or the built or natural environment (Nelson et al. 2015). Here, only few operational platforms exist to our knowledge (Nelson 2021) and most research is conducted on experienced safety hazards (Manton et al. 2016; Nelson et al. 2015). As such a participatory mapping tool could be integrated in the urban cycling dashboard to respect a local community's cycling experience, the following section will outline respective already existing research. For more detailed information on crowdsourcing data for cycling we refer to Nelson et al. (2021).

2.2.2 Participatory mapping of cycling experiences

We previously identified the need of including local cyclists' and their experiences into the planning and assessment of urban cycling. One way of actively generating such information as spatially referenced data is participatory sketch mapping (Manton et al. 2016; Marquart et al. 2020; Nelson et al. 2015; Pánek and Benediktsson 2017; Snizek et al. 2013). Sketch mapping utilizes a spatial accurate reference map as a base and generally serves as an alternative tool for collecting geospatial data mainly used for qualitatively capturing experiences in urban spaces (Boschmann and Cubbon 2014). Sketch mapping is one frequent methodology for emotional mapping, based on the underlying assumptions that emotions are closely linked to the experiences of the spatial environment (Poplin 2017). In the context of cycling, few academic studies exist that utilizes sketch mapping, either on paper or online, for mapping cycling emotions or their underlying cycling experiences and perceptions (Manton et al. 2016; Marquart et al. 2020; Nelson et al. 2015; Pánek and Benediktsson 2017; Snizek et al. 2013).

Besides paper sketch mapping applied for simple emotional mapping on cycling safety (Manton et al. 2016) and general good/bad cycling experiences (Marquart et al. 2020) there are two existing studies utilizing geospatial web-based applications on cycling experiences/emotions in Copenhagen, Denmark (Snizek et al. 2013) and Reykjavík, Iceland (Pánek and Benediktsson 2017). In both research studies participants were asked to digitally sketch their weekly routes, mapping positive or negative experiences along them and commenting on those with texts. By subsequently analyzing this data, both studies identified cycling streets and natural environments as best experienced, compared to worst perceived cycling at major roads with high traffic (Pánek and Benediktsson 2017; Snizek et al. 2013). However, the focus of these studies lays on the further statistical analysis on the spatially referenced cycling experiences in relation to their spatial environment. Their work revealed challenges in the actual handling of the mapping tools (e.g. locating emotions on a map), and the interpretation of the collected data (e.g. spatial reference, textual data without concrete categories) (Pánek and Benediktsson 2017; Poplin 2017; Snizek et al. 2013). Furthermore, Nelson et al. (2015) present a web-based geospatial tool for cycling citizens from all over the world to map their experienced safety hazards, near-misses and collisions. They hereby focus on properly collecting participatory data on cycling experiences or emotions, embedded in an Canadian research project (Nelson et al. 2015). Besides a sophisticated mapper asking questions about the incident details (e.g. time, injury severity, type of moving or stationary object), conditions (e.g. road conditions, bike infrastructure), and personal data (age, cycling frequency), the tool also visualizes the collected data and generates summary reports (Nelson et al. 2015).

However, those participative approaches in research are often merely seen as methods to collect spatially referenced data for following research analysis (Marquart et al. 2020; Milakis and Athanasopoulos 2014; Pánek and Benediktsson 2017; Snizek et al. 2013) but do not treat participation as the core research interest (Dunn 2007). In our context of GIScience, we actually understand participation as the empowerment of the local public and the inclusion of its local knowledge in complete decision-making processes. Greater attention to this issue of missing participation in GIS is demanded already from the late 1990s on (Harris and Weiner 1998; Pickles 1995). However, Marzouki et al. (2017) emphasize the

actual potential role of digital geovisualization during all steps of a citizen participation process, by increasing the accessibility, transparency, and credibility of information (e.g. on final plans or decisions). He argues that a geographical reference can give digital citizen participation a better living context (Marzouki et al. 2017).
To further foster the use of geospatial technologies for an integration of the local community and their cycling experiences it needs more research on participatory mapping tools that can be operationally integrated into the decision-making process on urban cycling (Barrero and Rodriguez-Valencia 2021; Manton et al. 2016; Marquart et al. 2020; Pánek and Benediktsson 2017; Snizek et al. 2013).

2.2.3 Assessing quality of urban cycling with spatial data

For a deeper understanding and assessment of the urban cycling quality, data must not only be available but be turned into useful information by further meaningful processing. In this context, already existing literature often introduces the concept of a city's bikeability (Lowry et al. 2012; Schmid-Querg et al. 2021). Here, many different methods and applications of a bikeability score exists that can among others include data about classical cycling infrastructure (e.g. intersection design for cyclists), structural mobility services (e.g. existence and accessibility of bike-sharing systems and its intermodal connection to other means of transport), up to more soft indicators as community-related bicycle culture (Schmid-Querg et al. 2021). The final score is either calculated for a complete city (Copenhagenize Design Company 2022) or can spatially be differentiated within an urban grid or between distinct areas (Lowry et al. 2012; Schmid-Querg et al. 2021). However, as one single score for a complete city does not match our identified need for a finer and city-intern assessment of an urban cycling system, we will further again resort to spatial data as it facilitates an urban cycling assessment that provides a spatially differentiated view of cycling within a city.
Therefore, we will subsequently outline recent methodologies on infrastructure-centered and user-centered spatial assessments of urban cycling and finally present the sustainability assessment of urban cycling by DGNB (Deutsche Gesellschaft für nachhaltiges Bauen) (2020) that will be applied in our conceptualized urban cycling dashboard.

Infrastructure-centered assessment

As cycling infrastructure plays a decisive role in determining the quality of urban cycling (Fernández-Heredia et al. 2014; Marquart et al. 2020; Milakis and Athanasopoulos 2014) it is obvious that especially spatial data of cycling infrastructure has been used for developing technical assessments of urban cycling quality (DGNB 2020; Kazemzadeh et al. 2020; Lowry et al. 2012; Schmid-Querg et al. 2021). Here, one possible assessment is called the bicycle level of service (BLOS), that is adapted from traditional street performance indicators that originally emerged from transportation planning for motorized vehicles (Barrero and

Rodriguez-Valencia 2021). While the original single BLOS score is introduced by Lowry et al. (2012), Kazemzadeh et al. (2020) categorize following studies on BLOS scores into a) the cycling flow, b) the cycling infrastructure, and c) exogenous variables. Although the grid-based results are spatially refined and include aspects of infrastructural accessibility, the predominant focus of a BLOS score lays on assessing the capacity of single linear segments along the cycling-in-practice infrastructure. Therefore, it often neglects connectivity of a whole infrastructural network, or also trip-end facilities and repair stations, that are considered as an important factor to enable flexible and comfortable cycling (Fernández-Heredia et al. 2014; Hull and O'Holleran 2014; Kazemzadeh et al. 2020; Snizek et al. 2013).

User-centered assessment

However, there is the on-going criticism that the assessment of urban cycling quality still often solely makes use of hard infrastructural data and instrumental methodologies (Barrero and Rodriguez-Valencia 2021; Liu et al. 2021; Marquart et al. 2020). Therefore, more recent methodologies exist that integrate the local cyclists' experience or emotions into their assessment. Here, Barrero and Rodriguez-Valencia (2021) with their bicycle quality of service indicator for Bogotá, Colombia, or Schmid-Querg et al. (2021) with their bikeability index for Munich, Germany, conduct spatial surveys with local cyclists and integrate them quantitatively into the computation of their final scores. Here, especially perceived safety (Barrero and Rodriguez-Valencia 2021; Ul-Abdin et al. 2019; Useche et al. 2018) but also level of stress (Furth et al. 2016) can be added as more user-centered components of the assessment. However, these approaches rely on an event-driven integration of cyclists and due to this work effort are spatially limited in their application area.

Sustainability assessment by DGNB

To assess the quality of urban cycling in our urban cycling dashboard we will resort to a criterion catalogue for the sustainability assessment of urban quarters in Germany developed by the DGNB (2020). Among 31 criteria this expert catalogue also presents a technical methodology for assessing the sustainability of cycling as an unmotorized individual mobility. Here, they refer to four indicator categories that are a) innovative mobility elements for promoting cycling (e.g. app-based information on parking, accessibility of a bike-sharing system), b) cycling infrastructure (e.g. cycling streets, connectivity of cycling network, accessibility of parking facilities), c) quality of parking facilities (e.g. weather or theft protection, accessible repair station), and d) a wayfinding system. Each category has its own maximum score to form a weighted total score at the end (DGNB 2020). As this sustainability assessment is developed for small scale urban quarters it fulfills the need for a spatially differentiated assessment within one single city. However, with some exceptions of soft data in the first indicator category (e.g. existence of app for parking information) it

is mainly based on spatial data of cycling infrastructure and therefore is not considered as a user-centered assessment.
For its application in our conceptualized urban cycling dashboard we resort to our cooperative bachelor thesis that proposes an automized implementation of this cycling sustainability assessment (Fermazin 2021). As this implementation solely relies on open source data from OSM (Fermazin 2021; Ferster et al. 2020), not all data is available to follow the exact methodology proposed by DGNB (Fermazin 2021). Therefore, the automized implementation by Fermazin (2021) is built upon a composition of single indicators from each indicator category.

To sum up this subchapter of using spatial data for urban cycling (p. 12-17), we identify a first gap of missing continuous data availability on cycling experiences such as cycling emotions. Additionally, we state a second gap on missing user-centered automated sustainability assessments of urban cycling.

2.2.4 Excursus: Smart solutions for urban cycling

The use of technologies and data for urban mobility is on steady rise majorly driven by recent improvements on ubiquitous internet access, easy accessibility of digital devices, paired with the widespread use of information communication, and GPS tracking technologies. In this context of constant data flows for urban smart solutions, attention is also paid to the recent trend of smart cycling not only in the private commercial sector but also in urban transportation research (Behrendt 2020; Nikolaeva et al. 2019; Popan 2019).
However, general smart mobility that promises safer, more efficient and more attractive mobility in cities (Oliveira et al. 2021) is so far mainly focused on motorized vehicles (e.g. strategy and policy papers by the European Commission), while cycling has long been perceived as an offline activity (Behrendt 2020; Nikolaeva et al. 2019). Here, Behrendt (2020) calls for a greater consideration of smart cycling solutions in planning the utopian urban mobility futures. As utopian thinking is a powerful method for presenting and shaping future, also cycling should be presented as a smart but sustainable mobility to create a more attractive and innovative image of cycling, that is worth to invest in (Behrendt 2020).
Smart solutions in cycling are strongly connected to the paradigm of the internet of things: Based on the wireless connection and communication between digital and physical infrastructure it provides automated and ubiquitous data collection, processing, and the final offer of automized services (Nikolaeva et al. 2019; Oliveira et al. 2021). While bikes can not only serve as a platform for collecting and processing data on environmental monitoring (e.g. pollution, temperature), or personal health monitoring (e.g. heart rate, travel distance), they can also communicate with further digital and physical infrastructure (e.g. traffic lights at junctions). This finally can result in exemplary applications as green

waves of signals for cyclists (Oliveira et al. 2021). While most applications serve the cyclists during actively cycling (Nikolaeva et al. 2019; Oliveira et al. 2021), smart cycling solutions can also support the general off-cycling collection, processing and sharing of cycling information (e.g. daily commuting routes) (Behrendt 2020; Oliveira et al. 2021).
However, alongside those promises there is also strong criticism on this smartification of cycling. Regarding a possible change of cycling behavior, Popan (2019) cautions that the sheer integration of smart solutions into the urban cycling could end in bicycles that are characterized by growth and speed. In the context of datafication of urban cycling, Nelson et al. (2021) mention challenges of data access and funding, data privacy, data representativeness and quality, and openness of analytical methods. Regarding these concerns, Nikolaeva et al. (2019) warn that the future of smart cycling can speed up the current trend of a neoliberalization in urban transportation systems. Here, Behrendt (2020) and Nikolaeva et al. (2019) emphasize the role of urban administrations and authorities to hold personal cycling-related data in official governments' hands rather than leave it to private companies. This data should be openly accessible to tangibly and justly serve individuals and society than ending in commercial products (Behrendt 2020; Nikolaeva et al. 2019). Simultaneously, as the availability of cycling-related data is rising rapidly, it exceeds current capacities of developing adequate analytical methodologies or platforms to turn this data into informative insights (Nelson et al. 2021). Additionally, Nikolaeva et al. (2019) and Behrendt (2020) call for greater respect to the social and political perspective of smart cycling. Political processes are so far either shaped as bottom-up approaches shifting the responsibility to the cyclist or shaped as top-down approaches from urban authorities. Here, further research on participatory smart solutions could bring those two groups together than split them (Nikolaeva et al. 2019). Additionally, the social aspect of smart cycling solutions (e.g. marginalization of communities) and corresponding concerns on data quality (e.g. representativeness) are important considerations for further academic works (Nelson et al. 2021; Nikolaeva et al. 2019).

In this context, we follow existing research and consider urban dashboards as a potential smart solution and technology (Jing et al. 2019; Lock et al. 2020; McArdle and Kitchin 2016) that can be applied as an innovative feature in the field of urban cycling. Here, we understand an urban cycling dashboard rather as a smart platform for monitoring a city's cycling quality and for communicating and exchanging information between decision makers and the cycling community, than offering an automized service during the act of cycling. However, the previously mentioned concerns on the datafication of urban cycling should be addressed in the development of an urban cycling dashboard.

2.3 Urban dashboards and cycling

The quest for transparency of urban governance (Estevez et al. 2021; Kitchin and McArdle 2017) and creating awareness for urban challenges (e.g. on sustainable mobility in cities), highlights the importance of adequately communicating and exchanging information between a city's various stakeholders (Popan 2019; Young and Kitchin 2020). Although urban data is nowadays often openly accessible (e.g. via municipal open data portals), it often lacks tools and literacy to turn this data into tangible knowledge. In this context, urban dashboards are considered as an important information communication technology (Young and Kitchin 2020). Therefore, this subchapter will subsequently 1) give a general overview of urban dashboards, 2) introduce the concept of user-centric design, 3) address participatory urban dashboards, and 4) finally outline the current use of urban dashboards in the field of cycling.

2.3.1 Goals and structure of urban dashboards

Urban dashboards emerged from efficient, mostly real-time monitoring of urban services and a city's performance for experts in industry or government. They utilize visual analytics as a combination of interactive visualizations (e.g. graphs, texts, maps, 3D models) and analytical approaches for investigating, analyzing, and eventually understanding urban data (Kitchin and McArdle 2017; Young and Kitchin 2020). Today urban dashboards are increasingly used by various urban stakeholders, also including the public, to foster openness and understanding of urban data, as well as the transparency of urban processes and decisions (Kitchin et al. 2015; Kitchin and McArdle 2017). Nowadays, a variety of operational urban dashboards are run by local authorities or research projects addressing the assessment of the urban systems as a whole or with distinct thematic focuses (e.g. retail market, culture, energy supply, or transport) (Jing et al. 2019; Lock et al. 2020; McArdle and Kitchin 2016).

Here Jing et al. (2019) present a three-part categorization of urban dashboards from a usage perspective into a) operational performance dashboards allowing the mere tracking of urban systems or services via indicators, b) analytical dashboards with a diagnostic approach allowing for spatial analysis to find patterns or relations between indicators or variable, and c) strategical dashboards enabling modelling and future predictions (Jing et al. 2019). According to this categorization we contextualize our urban cycling dashboard within the first group of operational performance dashboards.

Furthermore, Jing et al. (2019) and Kitchin and McArdle (2017) accordantly structure urban (geospatial) dashboards into four structural components of a) the underlying technical architecture, b) the content, c) the web design and layout, as well as d) the final data visualization techniques supporting the extraction of knowledge. Additionally, urban dashboards are naturally often linked to geospatial data and map visualizations (Brocza and

Kollarits 2020; Marzouki et al. 2017) which implies particular challenges in data modelling, assessment of indicators or visualizations (Jing et al. 2019; Kitchin and McArdle 2017). More detailed information on the structural components of urban dashboards is presented in the result subchapter 4.4 (p. 36-52) as findings from our literature and dashboard review 2.

2.3.2 User-centric design of urban dashboards

Kitchin and McArdle (2017) as well as Young and Kitchin (2020) point out that it does not lack the mere existence of urban dashboards anymore, but it lacks simple and frequently used urban dashboards. Although research on more public-centered urban dashboards is rapidly increasing, most existing tools are still designed for a user base of experts while the public lacks the digital literacy to handle those (Kitchin and McArdle 2017; Young et al. 2021; Young and Kitchin 2020). As the success and outcome of an urban dashboard depends on how well the application is adapted and used by the citizens or policymakers, user-centric design is crucial (Young et al. 2021; Young and Kitchin 2020). Here, Young and Kitchen (2020) highlight the current challenges in developing urban dashboards, such as missing empathy towards the intended users and a lack of user integration in the development phase. Therefore, they phrase general guidelines on the web design, visualization, and content of urban dashboards from a users' perspective to improve the usability (e.g. simple and efficient handling) and guaranteeing the utility (e.g. generating meaningful knowledge) of their Dublin Dashboard (Young and Kitchin 2020). As there is also a lack of systematic approaches on how to integrate different types of users into the planning and design process of urban dashboards, they also present an approach for identifying user persona (Young et al. 2021). In this context of user integration, Sardain et al. (2016) present a participative process to engage users in the initial development phase of a dashboard by conducting a workshop, a follow-up survey, and a final focus group meeting for the selection and prioritization of indicators. Regarding the participation a strong declination of participants was evident over time (Sardain et al. 2016).

However, it lacks systematic approaches for user-centric designs and developments of urban dashboards while also user integration does not end with a first implementation of an urban dashboard but continues in its maintenance and further development (Young and Kitchin 2020).

2.3.3 Participatory urban dashboards

Lock et al. (2020) point out that most urban dashboards are mainly characterized by a one-way flow of information. Here they highlight the gap of existing dashboards that enable a two- or multi-way flow of information between an urban dashboard and its users. Therefore, they study potential features and designs of participatory or collaborative modules that can be integrated in urban dashboards to collect user-generated data and account for it in urban decision-making (Lock et al. 2020). Here they highlight four key issues in future planning and design of participatory urban dashboards in a) where the participation happens, b) how user-generated data is collected, c) how this user-generated data is shared and visualized, and d) how this user-generated information is applied and turned into tangible outcomes. Also Jing et al. (2019) point out the importance of urban dashboards in the context of collaborative and evidence-based decision-making by integrating data generated by citizens directly.

However, there is a need for more investigation on how participatory urban dashboards can be used for enabling permanent and digital citizen participation in urban decision-making (Lock et al. 2020; Marzouki et al. 2017).

2.3.4 Urban cycling dashboards

In the previous background chapter we identified the following needs for future research on the urban cycling system: Operational and permanent collection of experience-based data by cyclists, open and centralized access to a variety of urban data related to cycling, and an automized assessment of the urban cycling quality including user-centered approaches. These research gaps go in accordance with the potentials of urban dashboards in increasing a city's transparency of urban data and decisions as well as with their needs for user-centric designs and participatory modules. Therefore, we suggest merging both theoretical concepts and conceptualizing an urban cycling dashboard to participatively generate cycling-related data, assessing it and transparently communicate it by interactive visualizations.

Here, we identified that most existing urban dashboards only rarely contain cycling-related data except single numbers of passing cyclists (Smart City Münster 2021a) or addressing the performance of bike-sharing systems (McArdle and Kitchin 2016). However, there is an on-going research project from the University of Salzburg on a so-called bicycle observatory for the city of Salzburg and the municipality of Wals-Siezenheim, both Austria. This project is still in the phase of development and no first implemented prototype exists yet (Brocza and Kollarits 2020; Leitinger et al. 2020; Loidl et al. 2020). Their bicycle observatory aims in supporting a better understanding of the urban cycling system for decision makers as well as for cyclists and citizens. As urban cycling is a complex and dynamic mobility system Loidl et al. (2020) highlight the potential of the bicycle observatory to enable a systematic approach to urban cycling rather than observing individual or aggregated phenomena. Therefore, they apply the concept of a geographical information observatory to provide a spatially differentiated and temporally continuous picture of cycling mobility (Brocza and Kollarits 2020; Loidl et al. 2020). Consequentially, single event-driven campaigns for generating insights into the urban cycling system are not sufficient. Therefore, a variety of continuous cycling-relevant data should be integrated into the dashboard, ranging from real time information (e.g. cyclists' counters or weather predictions), or information on experiences (e.g. on cycling safety), cycling infrastructure and trajectories, until qualitative mobility behavior studies. Utilizing interactive web maps, diagrams and infographics, this bicycle observatory should deliver a daily updated picture of a city's or municipality's cycling system (Brocza and Kollarits 2020; Loidl et al. 2020).

However, the variety of data sources and the resulting large amounts of data in one common platform raises technical challenges as the availability, accessibility, actuality and integration of the intended data (Loidl et al. 2020). Additionally, as different types of users with different skills and expectations will approach the bicycle observatory (e.g. news or fast facts for cyclists versus temporal analysis of trends for spatial planners) high requirements are set to an intuitive user experience within a clear structure. Here, they propose hierarchical tiles for an easy navigation during the explorative usage of the dashboard (Loidl et al. 2020).

However, besides a previous user study on identifying different types of cyclists, no further user integration is conducted within the conceptualization or development of the bicycle observatory. Additionally, they do not use their dashboard for collecting data from the users directly in a participatory way, as for example data on cycling experiences as safety hazards resort to official statistics (Brocza and Kollarits 2020; Loidl et al. 2020).

Besides this important research project, further tools exist focusing either on the participatory collection of cycling data (Nelson 2021) or the assessment of urban cycling quality (Copenhagenize Design Company 2022). However, they are not considered to be urban dashboards due to the lack of integrating a variety of cycling-related data, missing sets of indicators, or no visual analytics for explorative data analysis.

2.4 Cycling in Münster

As our case study on the conceptualization of an urban cycling dashboard is conducted in Münster, Germany, the following chapter briefly introduces cycling-related facts as well as already conducted research in Münster that is related to our work.

According to the German spatial planning hierarchy, Münster is a high-order city located in North-Rhine Westphalia inhabited by approximately 315 000 inhabitants (Schröder 2021). Münster is nationally as well as internationally known as a cycling city with famous infrastructural elements as the "Promenade", a green belt around the city center that is used as a bike highway (Schröder 2021). According to a mobility survey from 2019, 44% of all urban trips in Münster are made using bicycles (Stadt Münster 2020a). However, to get even more citizens cycling and due to partly outdated infrastructure, the local municipality aims in further increasing the bike-friendliness and bikeability in Münster (Lowry et al. 2012; Schröder 2021). Here, infrastructural developments of more cycling routes (e.g. "Promenade" along the canal (Stadt Münster 2021b)), newly planned cycling streets (Schröder 2021), as well as new parking racks in the city center (Stadt Münster 2021a) play an important role. Besides that, the municipality also conceptually advances cycling in

Münster for example by developing a categorized bike network 2.0 (Smart City Münster 2021b; Stadt Münster 2021c).
Within all these measures, citizens are participatively integrated but often more dispersed and punctually event-driven (e.g. citizen symposium (Stadt Münster 2016)), suggestions for parking racks (Stadt Münster 2021a), or periodic route-tracking during (Smart City Münster 2021b; Stadt Münster 2021c)). Therefore, citizen participation is not centrally and permanently organized (Fahrradbüro Münster 2022).
Furthermore, transparently communicating recent commitments, future projects or information on the current cycling infrastructure is of great importance for the municipality of Münster (Fahrradbüro Münster 2022). However, no central and interactive platform for cycling information is run by the municipality yet (Fahrradbüro Münster 2022; Smart City Münster 2022). Nevertheless, digital information can sparsely be found on Münster's smart city dashboard with daily counts of passing cyclists at various locations (Smart City Münster 2021a) or a web-map showing finalized, current and planned developments of cycling infrastructure (Stadt Münster 2020b). Recently, this web-map must be shut down due to municipality internal maintenance issues (Fahrradbüro Münster 2022). Besides that, non-interactive information on cycling infrastructure is additionally available on digital maps (Stadt Münster 2018).
Furthermore, existing research in the fields of urban transportation planning and GIScience used Münster as one case study next to Castellòn, Spain, and Valletta, Malta. Here, Pajarito and Maas (2018) present the potential of actively involving cyclists for crowdsourcing data with a mobile and gamified application that utilizes geospatial technologies to map and to visualize the cyclists' routes (Pajarito and Maas 2018). This crowdsourced data from commuting cyclists is subsequently also used to map most used routes as well as frictional places during cycling (Pajarito and Gould 2018). Finally, Pajarito et al. (2020) also highlight the advantages of collaborative geo-based and gamified applications compared to most commonly competitive applications (e.g. strava) while attracting new cyclists with innovative incentive offers (Pajarito et al. 2020). A central collection of Pajarito's research works related to Münster can also be found in his PhD thesis (Pajarito 2018).

3. Methodology

The study's methodology is built upon a synthesis of qualitative and quantitative methodologies that aim in capturing a holistic view of an urban cycling dashboard and its potential users (figure 1). The first literature review sets a theoretical base in our work focusing on indicators and assessment of (experienced) cycling quality. Its outcome are two sets of subfactors for each, cycling infrastructure and cycling emotions. These sets will subsequently be prioritized in the main methodology of a web-based survey together with questions about preferences and motivations to potential user groups of the urban cycling dashboard from our case study in Münster, Germany. Eventually, a second literature and dashboard review focuses on general architectural, data visualization, and web design aspects of this participatory urban cycling dashboard.

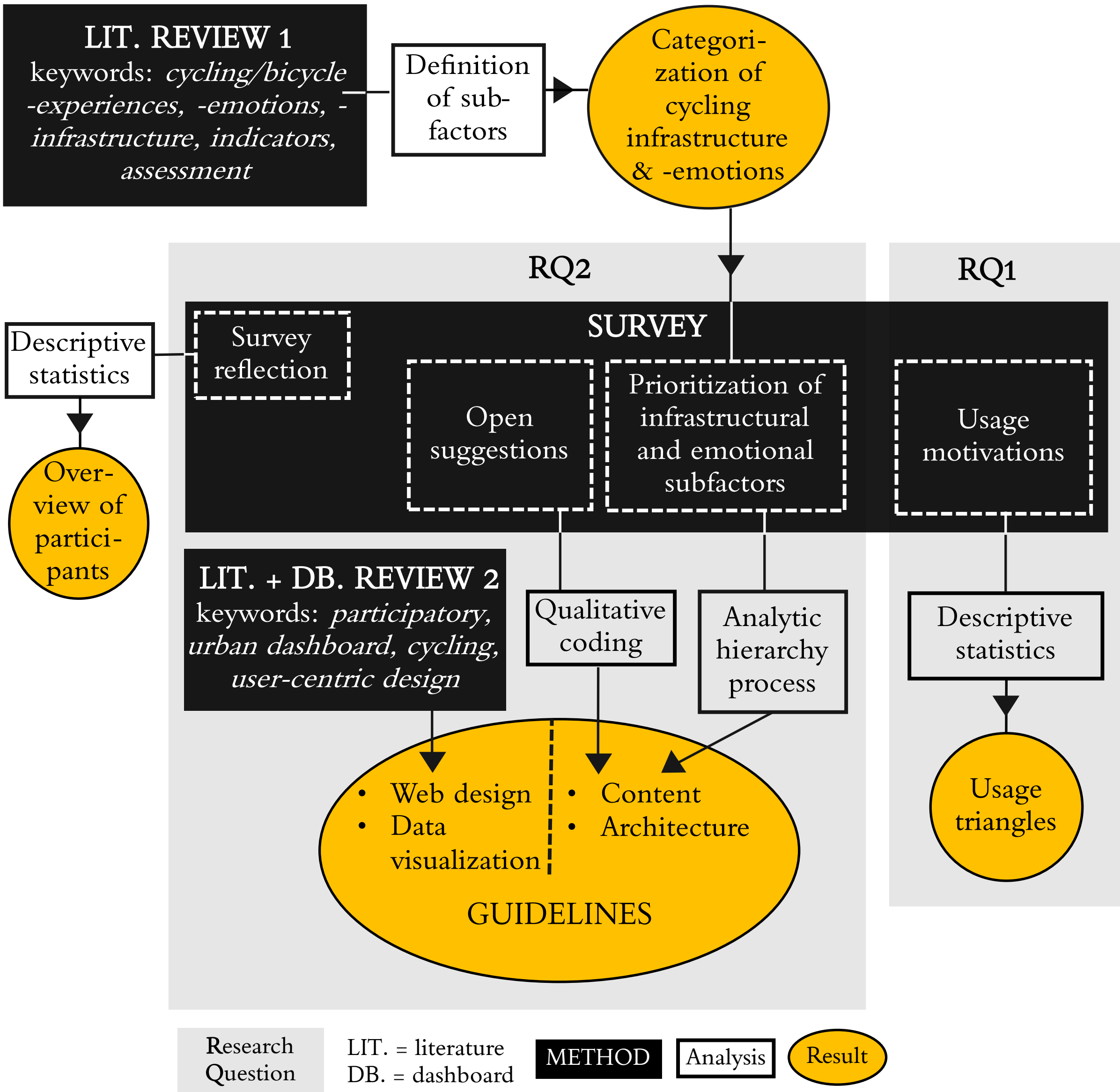


Figure 1: Methodological workflow including analytical steps and relation to the results

3.1. Literature review 1

In the background section we identified the need to include cycling experiences when sustainably assessing the urban cycling system. Therefore, this first literature review we derive sets of subfactors for both, physical cycling infrastructures and cycling emotions and contextualize both within the concept of cycling experiences.

We used the following keywords to search for literature on Google Scholar from September to November 2021: *Cycling/bicycle -experiences, -emotions, -infrastructure, indicators, assessment*. For deriving the set of physical components covering the cycling infrastructure we orientate at the previously mentioned criterion catalogue by DGNB. Its detailed criteria are developed by expert reviews and are commonly used as guidelines in planning processes and certifying the sustainability of living quarters. The criteria for cycling can be found in the technical category of infrastructure for non-motorized mobility (chapter *Tech 3.2* in DGNB 2020) and are already outlined in the background subsection 2.2.3 (p. 16-17). This cycling sustainability assessment has already been implemented in an automated way for Münster (Fermazin 2021). However, its indicators are refined by the literature review to finally form a set of subfactors describing the physical components of cycling infrastructure. For deriving a subfactor set of cycling emotions, we investigate current papers mainly from the field of urban transportation planning that overlap with GIScience. The reviewed key literature for categorizing cycling emotions and for locating it together with cycling infrastructure within the concept of cycling experience are shown in appendix A (p. 70-73).

The final categorizations are presented in the result chapter 4.1 (p. 31-33). Its subfactors are subsequently prioritized in the following user survey.

3.2 User survey

As dashboards have different users with different skills, expectations and motivations (Brocza and Kollarits 2020; Young et al. 2021), we form two coarse intended user groups for the urban cycling dashboard according to the main groups of stakeholders in the urban cycling system (Marquart et al. 2020): Cyclists/citizens (CC) and decision makers (DM). To integrate the future user groups into the development process of the urban cycling dashboard, we also use them as target groups for the following survey. This user integration is crucial during the conceptualization of urban dashboards to ensure its upcoming adaption and use (Young and Kitchin 2020). The web survey is written in German and is conducted in our case study in Münster. Therefore, the participants must fulfill the requirements of either having cycling experiences in Münster or being a decision maker in the cycling context of Münster.

Surveys are one of the most typical research methodology across a variety of academic disciplines, also in the fields of sustainable urban mobility research (Fernández-Heredia et al. 2014) combined with geoinformatics (Barrero and Rodriguez-Valencia 2021; Pajarito 2018), and human-computer-interaction (Lazar 2017). Surveys are generally used for descriptions of target groups by capturing their attitudes, awareness, or intents. Surveys are practical to collect data of larger populations and generate shallow but wide insights. Depending on its design a survey can generate both, qualitative and quantitative data and therefore allows to explore uncharted waters as well as drawing statistical conclusions. Besides these advantages surveys can drawback while not providing deep understandings, causing misunderstandings due to its self-administration, asking biased questions, or when capturing factual data. The qualities of a survey differ greatly. To ensure a high credibility of its results a survey need a proper development process, including 1) the questionnaires' design 2) a pre-testing phase, and 3) ensure a good and appropriate sampling strategy between random and targeted distribution (Lazar 2017). In the following sections, these three steps are addressed.

3.2.1 Survey design

In designing a survey there is a difference between the design of one single task/question and the structure of the whole survey. Tasks and questions must be written carefully, non-biased and easy to understand to ensure that the meaning of the responses cover the intentions of the researcher. The whole survey should be a logically structured composition of tasks/questions to enable a clear and effective participation (Lazar 2017). Therefore, this survey is divided into three sections: 1) Prioritization of cycling emotions and cycling infrastructure, 2) usage motivations of different dashboard purposes per target group and open suggestions, and 3) personal data and reflection of the survey. The complete questionnaire is shown in appendix B (p. 74-80).

Before the respondents start with the actual tasks, all participants are asked to select their role: CC, or DM (task 0). The first section of the survey asks for the prioritization of cycling infrastructure and cycling emotions. Here, first two category-internal prioritizations take place within the subfactors from cycling emotions and cycling infrastructure (task 1 and 2). This is followed by a single final prioritization task between the two categories of cycling emotions and cycling infrastructure (task 3). In this context of cycling aspects, Barrero and Rodriguez -Valencia (2021) show in their street survey that cyclists can prioritize different parameters of cycling. The second section of the survey asks CC and DM independently from each other about their motivations regarding different usages of the urban cycling dashboard (task 4). These usages cover the potential flows of information between the dashboard and the two intended user groups. Participants quantitatively estimate their motivation to 1) inform about static infrastructural data, 2) generating information by their own, and 3) receiving information from the other user group. Usage motivation two and three can be summarized as participative exchange of information between the user groups.

In this survey section participants are also given blank space for personal suggestions regarding the content and purpose of the urban cycling dashboard (task 5). The third and closing section collects personal data of each participant (age and frequency of cycling), as well as asking for a self-reflection of the survey to capture the credibility and willingness of their participation.

3.2.3 Pre-testing and sampling

A pre-testing of the survey is conducted remotely with three insiders followed by four live tests with potential participants in the form of think aloud sessions. Their comments and thoughts are considered to rebuild and fine-tune the design of the survey. Their responds are not taken as valid participations in the following data analysis.
As both two target groups, CC and DM are no specific and closed populations, the sampling of the survey will be non-probabilistic. Therefore, snowball sampling will be conducted to recruit as many respondents from both target groups as possible, following the scheme of oversampling (Lazar 2017). For this recruiting of participants, e-mails with an explanation of the research and the link to the web survey are sent to the following institutions:

- City departments of Münster: *Mobilitätsplanung Stadt Münster*, *Fahrradbüro Stadt Münster*, *Smart City Stabsstelle Stadt Münster*, *Wissenschaftsbüro Stadt Münster*
- Cycling advocacy clubs: *Interessensgmeinschaft Fahrradstadt Münster e.V.*, *VCD Regionalverband Münsterland e.V.*, *ADFC Kreisverband Münsterland e.V.'*
- Research departments at WWU Münster: Professors and students from *Institute for Geoinformatics, Institute for Geography, Institute for Landscape Ecology'*
- Others: Newsletter of the *Allgmeiner Studierendenauschuss Münster*

3.2.3 Analysis of the survey

Before the actual analysis of the survey, every task-related respond is checked for its validity. The validity conditions are shown in the appendix C (p. 81). The subsequent analysis of the cleaned data is structured in 1) the analytic hierarchy process (AHP) of the prioritizations, 2) aggregation and visualization of motivation of usage purposes, 3) coding of the qualitative data. We utilize the open-source programming language R for automating the analysis of the survey respondents. The following R packages are used: *tidyverse* (Wickham 2021), *ahpsurvey* (Cho 2019), as well as for plotting *networkD3* (Allaire et al. 2017 p. 3) and *fmsb* (Nakazawa 2021).

Prioritization with AHP

Subsequently we will briefly introduce the general AHP and follow by describing its application in our study. Decision-making between several options is naturally hard to be tangibly assisted by numbers. Therefore, the AHP was developed for assisting this decision-making based on relative priorities of the underlying criteria. These relative priorities are derived from a matrix of pairwise comparisons, where every criterion (in our survey every subfactor) is prioritized against every other criterion (subfactor). Each pairwise prioritization is based on a numerical judgment that ranges from 1 (equal importance), 3, 5, 7, to 9 (extreme importance), with four intermediate steps at 2, 4, 6, 8. In perspective from the neglected criterion the reciprocals of each number (e.g. 1/5) gives its corresponding minor prioritization (Saaty 1990, 2008). As a proper validation cannot be conducted due to missing reference data, a consistency ratio is calculated to estimate the accordance between the aggregated pairwise prioritizations. A consistency ratio lower than 0.1 indicates consistent and reliable relative priorities of the criteria (Saaty 1990). Despite the criticism of using and even aggregating personal judgements, several real-world applications and credibility studies prove the AHP's reliability (Saaty 2008).

In this survey, participants are asked to prioritize the categories of cycling infrastructure and cycling emotions as well as their respective subfactors based on a scale from 1 to 5. By omitting the intermediate steps we use a less extreme scale for an easier handling of the task. Hereby, we simultaneously increase the consistency, but the resulting priorities show less differences. We use the R package *ahpsurvey* for the statistical analysis of the prioritization tasks (task 1-3) from the survey (Cho 2019). The following steps are conducted for the prioritization of the subfactors for cycling infrastructure and cycling emotions (task 1 and 2), separated by the user group of CC and DM:

1. Generate a list of single pairwise comparison matrices for every respondent and fill missing pairwise comparisons with the function *ahpsurvey::ahp.missing* (Harker 1987). Although imputing missing values should be avoided it is a reasonable action if its amount is relatively small (Cho 2019).
2. Calculate the individual preferences of each respondent with the function *ahpsurvey::ahp.indpref* using the method of principle eigenvalues (Saaty 2003) and calculate the corresponding consistency ratios with the function *ahpsurvey::ahp.cr* (Saaty and Tran 2007).
3. Transforming inconsistent pairwise comparison matrices using the function *ahpsurvey::ahp.harker* that if necessary adapts up to n-most (maximum of 2) inconsistently compared pairs within each pairwise comparison matrix (Harker 1987; Saaty and Tran 2007).
4. Computing the aggregated preferences per subfactor with *ahpsurvey::agg.pref* using the method of principle eigenvalues and aggregating the single priorities with an arithmetic mean (Saaty 2003).

For the prioritization between the categories of cycling emotions and cycling infrastructure (task 3) only steps 1 and 4 are applied as no consistency ratio can be calculated when only one single comparison between two criteria is made.

Aggregation and visualization of usage motivations
Section two of the survey asks the participants about their motivations of different usage purposes of the dashboard. Here, the participants estimate their motivation of three different usage purposes between 0 and 100. The responds are statistically aggregated using a robust median for averaging. The results are presented in a radar or spider chart using the R package *fmsb* (Nakazawa 2021). This type of visualization is commonly criticized (Holtz 2018). However, as in our case the radar or spider chart only depicts three variables (the three usage motivations), the shape of a resulting triangle even supports the comparison of different usage motivations between DM and CC.

Coding of qualitative suggestions
The second section also asks the participants for open suggestions regarding the content and purpose of the urban cycling dashboard (task 5). These qualitative comments can provide deep, detailed, and surprising insights due to its open frame. However, no statistical analysis can be performed on the raw textual data to turn it into summarized information (Lazar 2017; Marquart et al. 2020). Therefore, we process this textual data using qualitative coding where each comment is labeled in different categories to synthesize the single comments (Linneberg and Korsgaard 2019).
First, the comments are cleaned whether they fit in the intended frame of responds and are relevant to this research or not. Subsequently, the distinct categories of codes are derived mainly deductively (Linneberg and Korsgaard 2019) from previous findings of the background section and the literature review 1. However, as we want to keep our framework open and gain unexpected insights, some codes are inductively created or complemented.
The first code category *CODE.PURPOSE* orientates at the different usage motivations (task 4) of informing about static infrastructural data or dealing with participative data (generating or receiving information). Additionally, two code categories cover suggestions on possible content of the urban cycling dashboard. The more general category *CODE.CONTENT1* classifies the suggestions if possible either to the category of cycling emotions or to cycling infrastructure. The more detailed code category *CODE.CONTENT2* categorizes the comments to subfactors of the two categories or inductively adds further content-related codes. Complementary, one last code category *CODE.SPECIFIC* is used to label critique or special comments (e.g. map-visualization, data description, transparency, personalization). The coding is performed in two cycles while codes from both survey groups, the CC and DM are processed together.

3.3 Literature and dashboard review 2

After conducting the user survey another literature review in conjunction with a review of existing urban dashboards and participatory cycling platforms is performed.

For the literature review we used the following keywords on Google Scholar from September to January 2021: *Participatory, urban dashboard, cycling, user-centric design*. We already mentioned in the background section 2.3.4 (p. 21-22) that urban cycling dashboards are a rarity. Therefore, we focus on research that either generally evaluates existing urban dashboards regarding their structural components of architecture, data visualization, and web design or on research that conceptually develops urban cycling dashboards. The key literature is shown in appendix D1 (p. 82-84).

This unsystematic literature review will be completed by personal reviews of already existing urban dashboards or online platforms that specifically focus on cycling and citizen participation. According to our German case study we also focus our review on existing German-speaking urban dashboards or online platforms and highlight local implementations related to Münster. We approached the urban dashboards and online platforms between September 2021 and January 2022 and list the relevant ones in appendix D2 (p.85).

4 Results

The result chapter is structured in order of our conducted work stages. First and based on the literature review 1, the categorization of cycling infrastructure and cycling emotions is introduced naming their corresponding subfactors and locating it within the concept of cycling experiences. Second, an overview about the participation at the user survey from Münster is presented. The third subchapter addresses RQ1 and the motivation of different usage purposes for the urban cycling dashboard that were estimated by both user groups in the survey. The fourth and last subchapter focuses on RQ2 and will present guidelines for the urban cycling dashboard regarding its structural components of content, architecture, data visualization, and web design. This last result is based on findings from the user survey as well as from literature and dashboard review 2.

4.1 Categorization of cycling infrastructure and emotions

The results from this chapter are based on literature review 1 that aims in 1) finding subfactors of cycling infrastructure and cycling emotions and 2) contextualize both in the context of cycling experience.

This is an important step in the development of our participatory urban cycling dashboard for three reasons. First, it sets the frame for the automated assessment of the central indicator score that helps to monitor the quality of cycling infrastructure in our urban cycling dashboard. Second, clear subfactors of cycling emotions must be found to realize its desired integration into the sustainability assessment of the urban cycling. Third, clear and distinct meanings of the categories of cycling infrastructure and cycling emotions and their corresponding subfactors are essential for a comprehensive exchange of information between the user groups. This is especially important as a non-present and digital communication on the urban cycling dashboard is prone to misunderstandings (Lock et al. 2020). However, now first we briefly outline the research background of cycling experience.

Conceptual background of cycling experience

This subchapter aims in locating our two categories of cycling infrastructure and cycling emotions within the concept of cycling experience. Both categories of cycling infrastructure and cycling emotions have a natural high relationship, as in many infrastructural manuals, guidelines, or strategical papers the optimum of a high-quality cycling infrastructure is mostly expressed by emotions (BMVI 2021; DGNB 2020). In the DGNB (2020) catalogue it is exemplary stated: “Cycling [should be] fast, safe and comfortable”. This shows that the terms, concepts and descriptions of cycling experience together with cycling emotions, and cycling infrastructure are often used interchangeably in previous research (Manton et al. 2016; Pánek and Benediktsson 2017; Snizek et al. 2013).

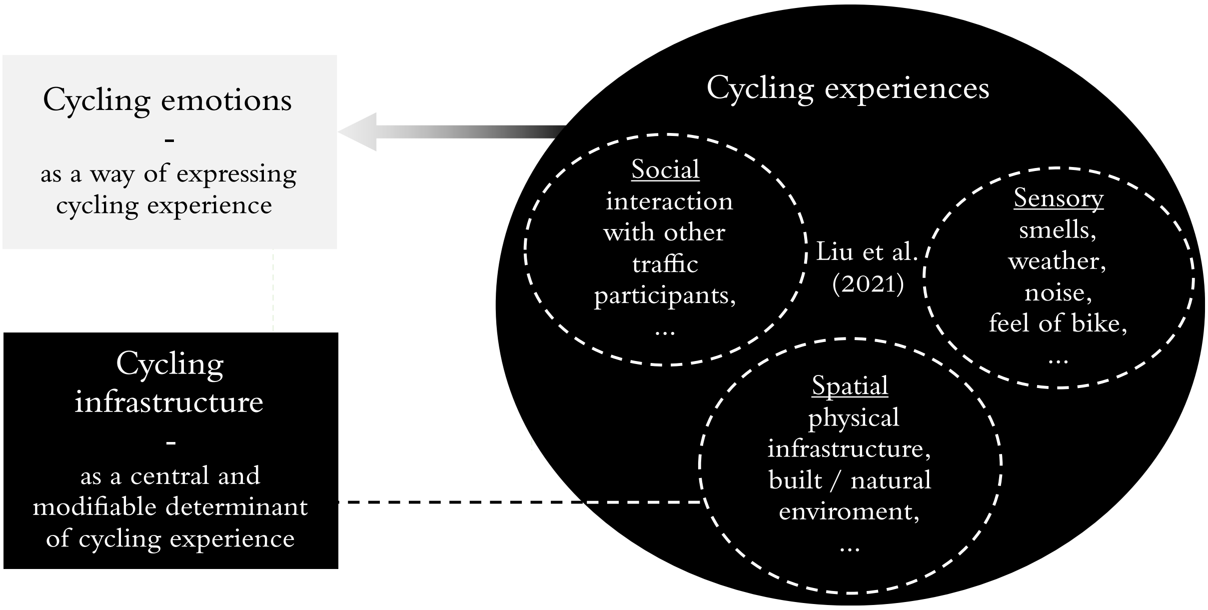


Figure 2: Locating cycling emotions and cycling infrastructure in the concept of cycling experiences

Figure 2 shows that in our understanding cycling emotions are the results from what a cyclist can perceive (Poplin 2017) during her or his trip - the cycling experiences. Following mainly Liu et al. (2021) there are three groups of cycling experiences: a) the spatial, b) the social, and c) the sensory. The spatial experience contains perceptions on the built (e.g. urban density or land use) and natural environment (e.g. water bodies, urban parks, elevation) (Fernández-Heredia et al. 2014; Marquart et al. 2020; Pánek and Benediktsson 2017; Snizek et al. 2013). Here, Liu et al. (2021) also include the perception of the cycling infrastructure. Besides these material experiences, Liu et al. (2021) present two further categories of possible cycling experiences. The social perception refers to interactions with other traffic participants, the perception of the quality of a passed neighborhood or observing the socio-economic characteristics of co-cyclists. The sensory perceptions account for direct human sensing as smelling, hearing noise, or feeling the weather (Liu et al. 2021). All those experiences do not stand alone but naturally influence each other and many of the perceptions are unplannable while some (e.g. cycling infrastructure) can be more modified (Liu et al. 2021). For summary, the cycling infrastructure is one central perception of forming a holistic cycling experience and cycling emotions are one way of subjectively expressing this cycling experience.

Cycling infrastructure

Probably the most important determinant of cycling experience, that can also be modified by spatial planning (Hull and O'Holleran 2014; Liu et al. 2021) is cycling infrastructure. As already mentioned within the background section 2.2.3 (p. 16-17) and the methodology subchapter 3.1 (p. 25) we orientate at the DGNB (2020) in accordance with other papers from literature review 1 to select the following subfactors for this category:

1) On-cycling factors:
   - Network of cycling lanes (e.g. connectivity of a cycling network and connection to networks of higher order)
   - Priority of cycling (e.g. dedicated cycling streets)
   - Traffic adaptions for cyclists (road and traffic adaptions for integrating easy cycling, e.g. cyclists traffic signals, separated cycling paths)
2) Off-cycling parking:
   - Parking options (e.g. availability and accessibility)
   - Quality of parking (e.g. theft protection or weather protection)
3) Cling services:
   - Wayfinding signs (e.g. density and quality)
   - Repair stations (e.g. availability, accessibility, and equipment)

These subfactors of physical components of cycling infrastructure are subsequently prioritized in the survey based on the cyclists' experiences but are assessed as indicators with spatial data according to the proposed automated assessment by Fermazin (2021).

Cycling emotions

While already approaches exist to capture single cycling emotions (Furth et al. 2016; Manton et al. 2016; Ul-Abdin et al. 2019; Useche et al. 2018), in our context of developing an urban cycling dashboard it is essential to first find out what can be captured in order to integrate cycling emotions. Here, we could identify in our literature review 1 the use of either simple valuing (e.g. 'good' or 'bad') (Pánek and Benediktsson 2017; Snizek et al. 2013) or more defined emotions (e.g. 'safe', 'enjoyable' , 'stressful', 'healthy', 'relaxing') (Barrero and Rodriguez-Valencia 2021; Fernández-Heredia et al. 2014; Hull and O'Holleran 2014; Marquart et al. 2020). In our selection of emotional subfactors we respect to guarantee more specification than 'good' or 'bad' but not getting to differentiating. We additionally phrased the emotions in a positive way so that they can be prioritized easier and more understandable in the user survey (e.g. relaxation also covers the emotion of stress in its negative). Eventually we come up with following emotions:

- happiness (e.g. triggered by attractiveness and liveliness of the surrounding)
- relaxation (e.g. health supporting and relaxation by greenness)
- fastness (e.g. fast commute without many stops)
- safety (e.g. few conflicts with other traffic participants)
- comfort (e.g. comfortable routes with nice material)

However, this selection of emotional subfactors is only a conceptual framework. If and how this category of emotions should be integrated into the urban cycling dashboard, will be addressed in result chapter 4.4.1 (p. 36-43).

4.2 User survey participations

As mentioned in the background section the integration of the intended user groups into the development and conceptualization of a dashboard is an essential step in ensuring later utility and usability (Young et al. 2021; Young and Kitchin 2020). Therefore, we asked our two intended user groups, the CC and the DM about their role-based opinions, expectations, and suggestions in a web-survey, that lasted approximately 15 minutes and is described in detail within the methodology section 3.2 (p. 25-29). All results are only valid for the urban cycling system of Münster. The survey has been live for one month between the 24th of November 2021 until the 23rd of December 2021.

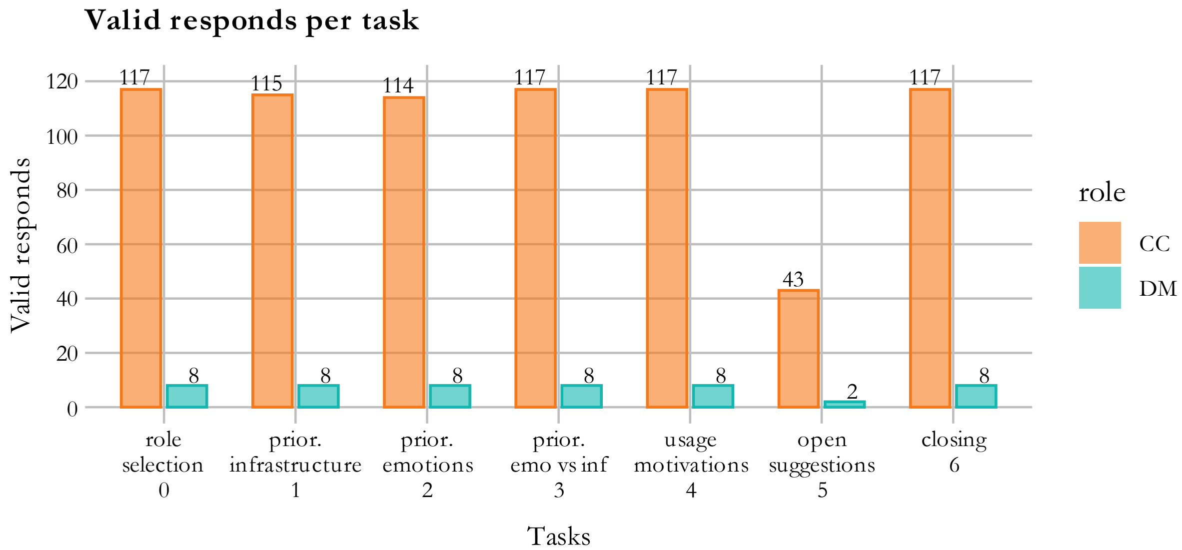


Figure 3: Valid responds per task of the user survey

Figure 3 shows the number of valid responds for the different tasks in the survey. 125 respondents (117 CC and 8 DM) chose a role (task 0) and validly completed the prioritization between cycling infrastructure and emotions (task 3) as well as estimated their usage motivations (task 4) and answered all closing questions. The category-internal prioritizations for cycling infrastructure (task 1) and for cycling emotions (task 2) were not validly filled out by all CC. The opportunity of giving open suggestions for the urban cycling dashboard (task 5) was used by 42 CC and two DM.

Figures 4 and 5 (p. 35) show results from the closing questions and describe the survey participants in their cycling frequency and their age. Figure 4 shows that a clear majority of the participants use their bike every day supplemented by almost the remaining participants who use it several times a week. While every age group is represented in the survey, figure 5 shows that especially young adults participated.

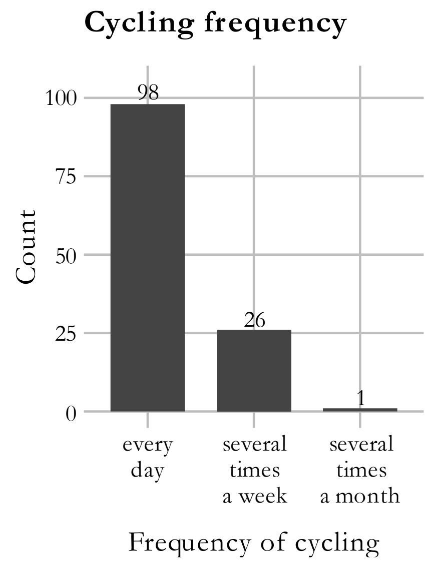


Figure 5: Cycling frequency of the survey participants

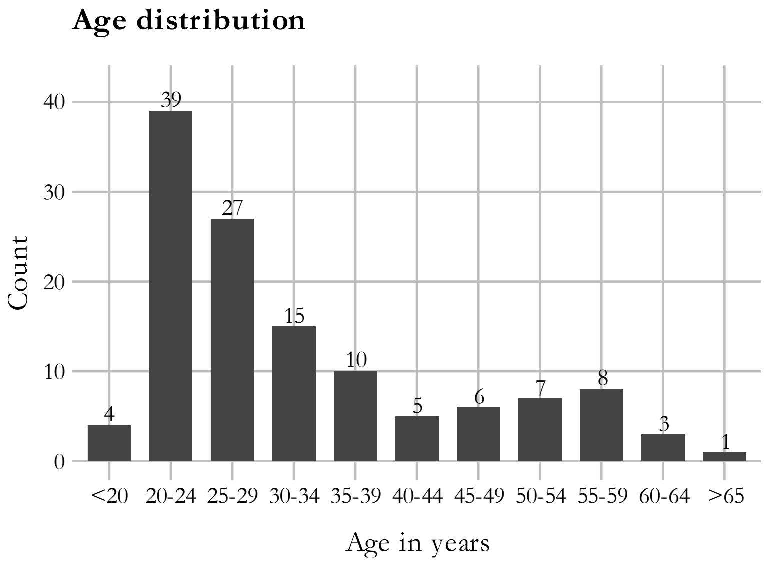


Figure 4: Age distribution of the survey participants

4.3 Usage motivations by user groups

In our background section we highlighted the potential of integrating citizens and cyclists within the planning of the urban cycling system. Therefore, we also decided to include participatory elements into the urban cycling dashboard from the outset. So, we can now establish two general flows information in our urban cycling dashboard. First, in a traditional view of urban dashboards, it transparently communicates information about the static data on cycling infrastructure. This one-way flow of information (from the dashboard to the user) (Lock et al. 2020) results in a dashboard usage of *informing about static data*.
Second, this basic structure is extended by using the dashboard in a participative way so that it serves as a platform for the exchange of user-generated information between cyclists or citizens and decision makers. This two-way flow of information (back and forth between the dashboard and the users) (Lock et al. 2020) results in two dashboard usages for each user group: *Generating information* for the other user group and *receiving information* from the other user group. In our user survey we asked the two user groups of CC and DM about their motivations of these resulting three different usages.
Figure 6 (p.36) shows the resulting two usage triangles for each user group (the boxplots for the usage motivations are shown in appendix E1 for CC and E2 for DM, p. 86). The oppositely directed tips give the motivation of each user groups to use the urban cycling dashboard for informing about static data (one-way flow of information). While the flat sides facing each other in the middle, capture the motivations of using the urban cycling dashboard in a participative way to exchange user-generated information (two-way flow of information). The left usage triangle for CC shows a clear tendency towards a participative

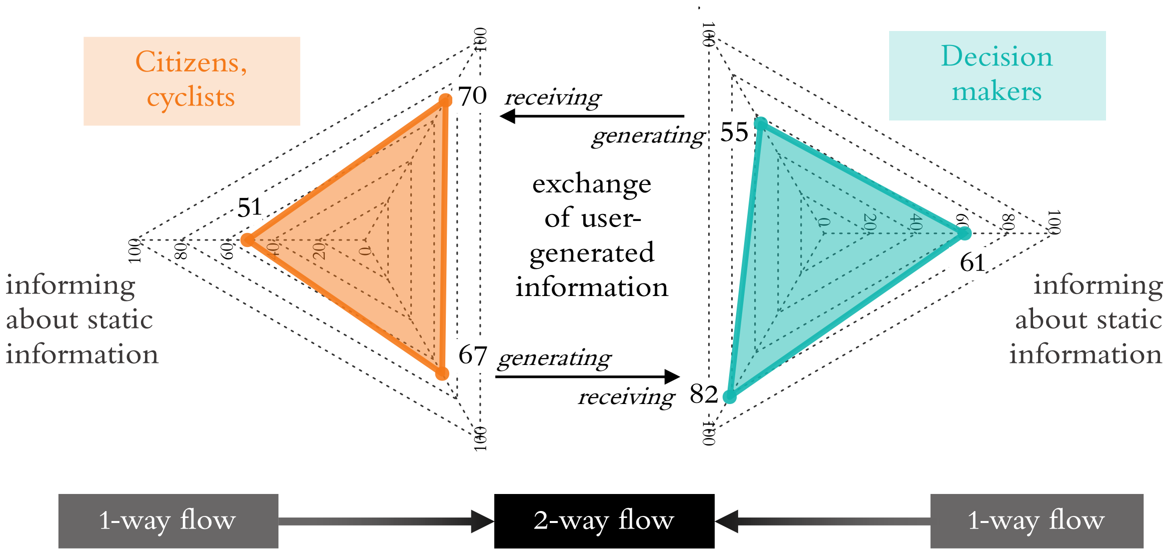


Figure 6: Estimated usage motivations by user group

usage and exchange of information with the DM. Here the motivation of receiving information (70) from the DM (e.g. on planning strategies, progress of constructions) is slightly higher than generating information (67; e.g. mapping cycling experiences or reporting deficiencies). CC show clearly less motivation to use the dashboard only to inform (51) about the spatial characteristics of the cycling infrastructure. The blueish colored usage triangle for DM on the right shows one clearly prioritized motivation of receiving information (82) from the CC (e.g. votes of future planes or mapped cycling experiences). Besides that, the motivation of informing (61) about the spatial characteristics of the cycling infrastructure is slightly higher than generating data (55; e.g. communication of planning strategies, constructions, infrastructural innovations). This focused motivation of DM is different compared to the generally preferred participative usage of the CC. Additionally, we also state that there are discrepancies within each exchange of user-generated information. Both user groups rate the usage of receiving information as most important and therefore expect the opposite user group to generate this information. But this corresponding usage of generating information is rated lower by both the CC and the DM.

4.4 Guidelines on structural components of the urban cycling dashboard

This chapter aims in elaborating guidelines for an urban cycling dashboard in Münster by applying the site-specific survey results and including the findings from the literature and dashboard review 2. The subchapter is organized by the four structural components of content, architecture, data visualization, and web design.

4.4.1 Content

This section focuses on building a frame of content for the urban cycling dashboard. It first presents the user survey results of the prioritizations between the categories of cycling emotions and infrastructure with their corresponding subfactors. It secondly consults information from the open suggestions made by CC and DM. Finally, it will present the general content-related orientation of the urban cycling dashboard and suggests possible core modules and their functionalities.

Prioritizations between cycling infrastructure and cycling emotions

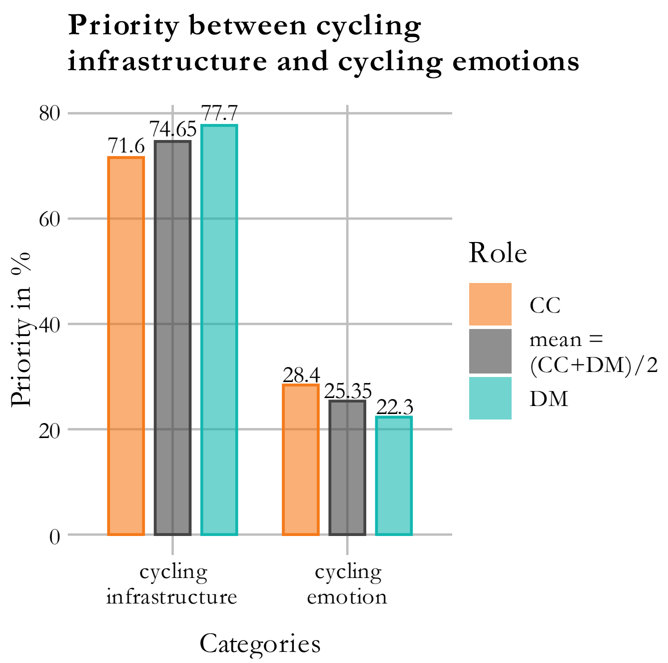


Figure 7: Priorities between cycling infrastructure and cycling emotions by survey group and their mean values

First, the general prioritization between the two main categories of cycling infrastructure and cycling emotions is presented. Followed by a closer look on the category internal prioritizations of the cycling infrastructures and the cycling emotions.

Figure 7 shows the prioritization between the categories of cycling infrastructure and cycling emotions by the survey group (orange for CC and blue for DM) and the resulting mean values (appendix F1 with boxplots of single prioritizations per category and survey group, p. 87). It is evident that cycling infrastructure is clearly more important for both user groups, CC, and DM, than cycling emotions. However, the CC rated cycling emotions slightly higher (CC: 28.4%) than the DM (22.3%).

Prioritizations of cycling infrastructure

Table 1 shows priorities of subfactors from cycling infrastructure summed up to the main groups of a) on-cycling (subfactors: traffic adaptions, cycling network, and cycling priority), b) off-cycling parking (subfactors: parking options and quality of parking), and c) cycling services (subfactors: wayfinding signs and repair stations). Table 1 shows that in general, on-cycling subfactors are most important for both survey groups of CC and DM, followed by

Table 1: Summed priorities for main groups of cycling infrastructure

Survey group	Sum of on-cycling subfactors	Sum of off-cycling parking subfactors	Sum of cycling services
CC	61.4%	22.0%	16.6%
DM	60.9%	26.0%	13.1%
Mean	61.15%	24.0%	14.85%

the two

subfactors for off-cycling parking and the least important subfactors of cycling services. However, besides the near parity of weights for on-cycling infrastructure between CC (61.4%) and DM (60.9%), we can detect a difference in weights between the CC and DM at the comparison of off-cycling parking subfactors and cycling services. Here, DM give off-cycling parking (26.0%) a higher priority of 12.9% than to the cycling services (13.1%), while the difference between the more important off-cycling parking (22.0%) and cycling services (16.6%) for CC amounts to only 5.4%.

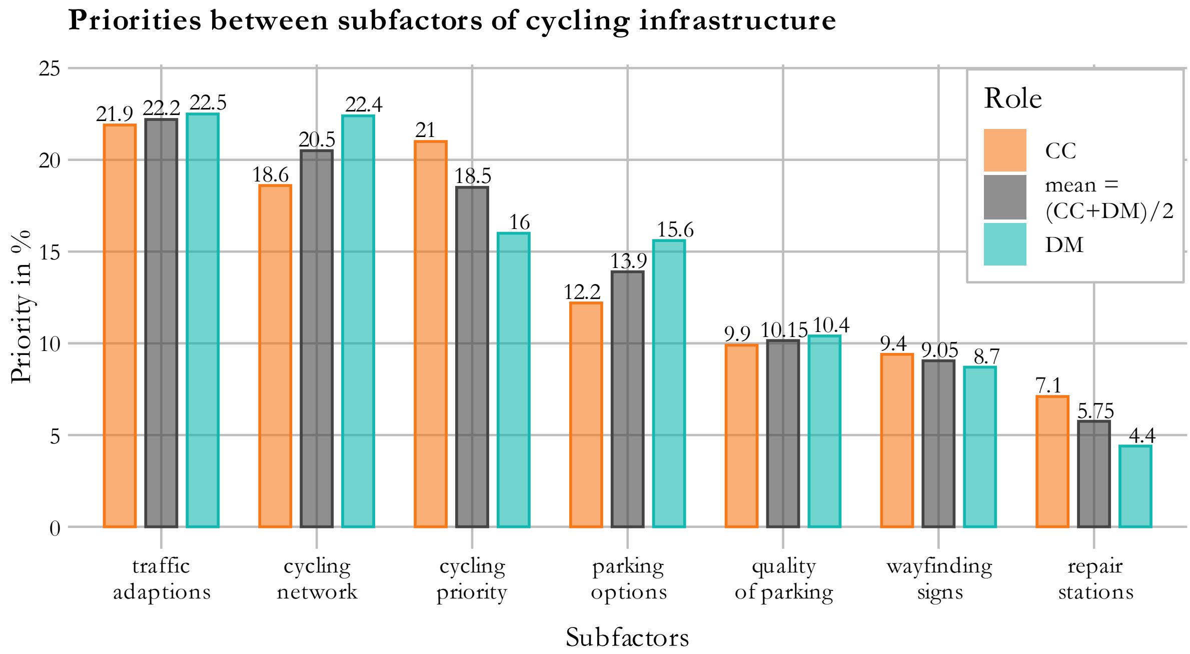


Figure 8: Priorities between the subfactors of cycling infrastructure by survey group and their mean values

More differences between CC and DM in the priorities of subfactors for cycling infrastructure can be found on the level of the seven single subfactors. Figure 8 shows the prioritization of the seven subfactors of the cycling infrastructure per user group and ordered by the resulting mean values (appendix F2 with boxplots of single prioritizations per subfactor and survey group, as well as number of (in)consistent prioritizations, p. 87). While traffic adaptions for integrating cyclists is most important for both survey groups of CC (21.9%) and DM (22.5%) there is a contrasting effect within the priorities for cycling priority and cycling network. CC prioritize cycling networks (18.6%) lower than cycling priority (21.0%). On the contrary, for DM cycling network (22.4%) is more important than cycling priority (16%). For the second main group of off-cycling parking, the subfactor of parking options is ranked as more important than the subfactors of parking quality for both survey groups. However, the accessibility and availability of parking options is ranked higher by DM (15.6%) than by CC (12.2%). For the last main group of cycling services, the subfactor of wayfinding signs is ranked as more important than the subfactor of repair stations for both survey groups. Here, especially the subfactor of repair stations show a difference of priorities between DM (4.4%) and CC (7.1%).

Prioritizations of cycling emotions

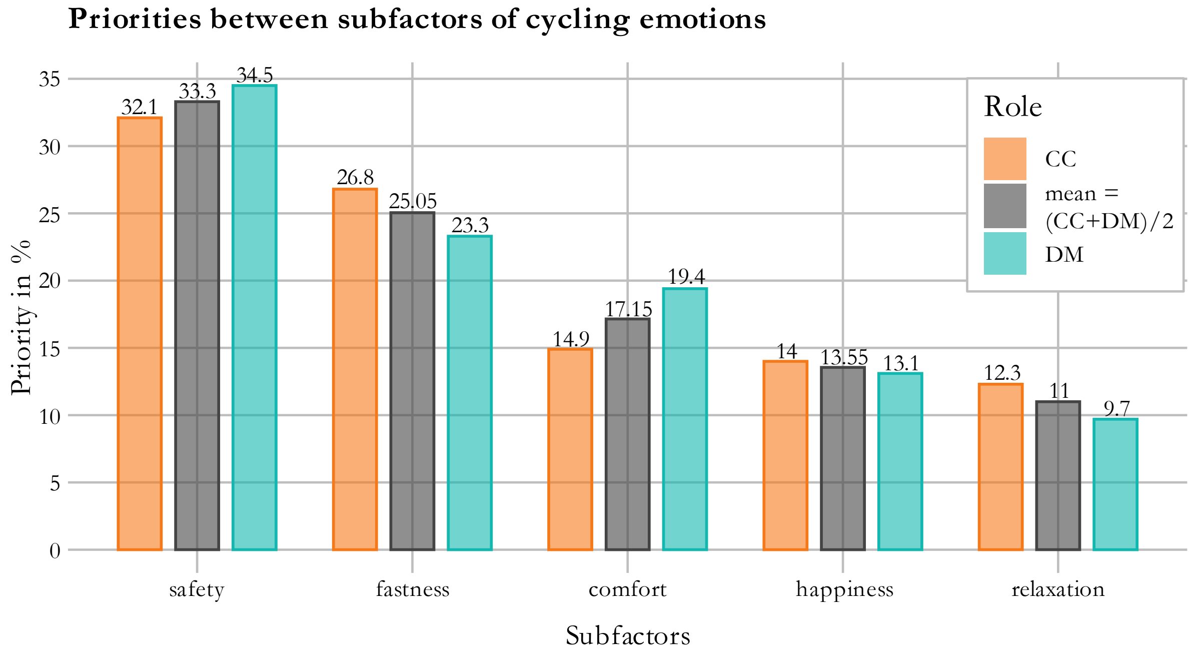


Figure 9: Priorities between the subfactors of cycling emotions by survey group and their mean values

Figure 9 shows the prioritizations of the five subfactors of cycling emotions for both user groups ranked by the corresponding mean values (appendix F3 with boxplots of single prioritizations per subfactor and survey group, as well as number of (in)consistent prioritizations, p. 88). For both user groups the priorities of emotions are ranked in the same order and show approximate equal weights. Following the mean values, safety (33.3%) is most important followed by fastness (25.05%), comfort (17.15%), happiness (13.55%), and relaxation (11.00%). However, the range of weights is more extreme for DM than for CC, as the highest priority of safety is weighted more by DM (34.5%) compared to CC (32.1%) and the lowest priority of relaxation is weighted lower also by the DM (9.7%) compared to CC (12.3%). Additionally, fastness is more important for CC (26.8%) than for DM (23.3%) while comfortable cycling is weighted higher by DM (19.4%) than by CC (14.9%).

For summarizing the results of all prioritization we only account for the mean values of priorities between CC and DM. According to the general prioritization between cycling infrastructure and emotions, the core content of the urban cycling dashboard will lay on the cycling infrastructure, and here more on on-cycling subfactors, than on off-cycling parking and last cycling services. However, we see cycling emotions not as clearly rejected and therefore will respect it also in our urban cycling dashboard but not integrate it into the automated assessment of indicators.

Open suggestions

Besides the previous prioritizations, the second noticeable outcome from the survey to shape the content of the urban cycling dashboard are the open suggestions. After removing four non-relevant comments, a total of 80 suggestions are mentioned by 39 CC, and four suggestions are made by two DM (see all coded open suggestions in the appendix, p. 89-98). Such an open-framed question gives the future users the opportunity to suggest concrete ideas as functionalities or information that they expect to find in an urban cycling dashboard. Due to the small number of suggestions from DM all open suggestions are analyzed together regardless of whether they are made by CC or DM.

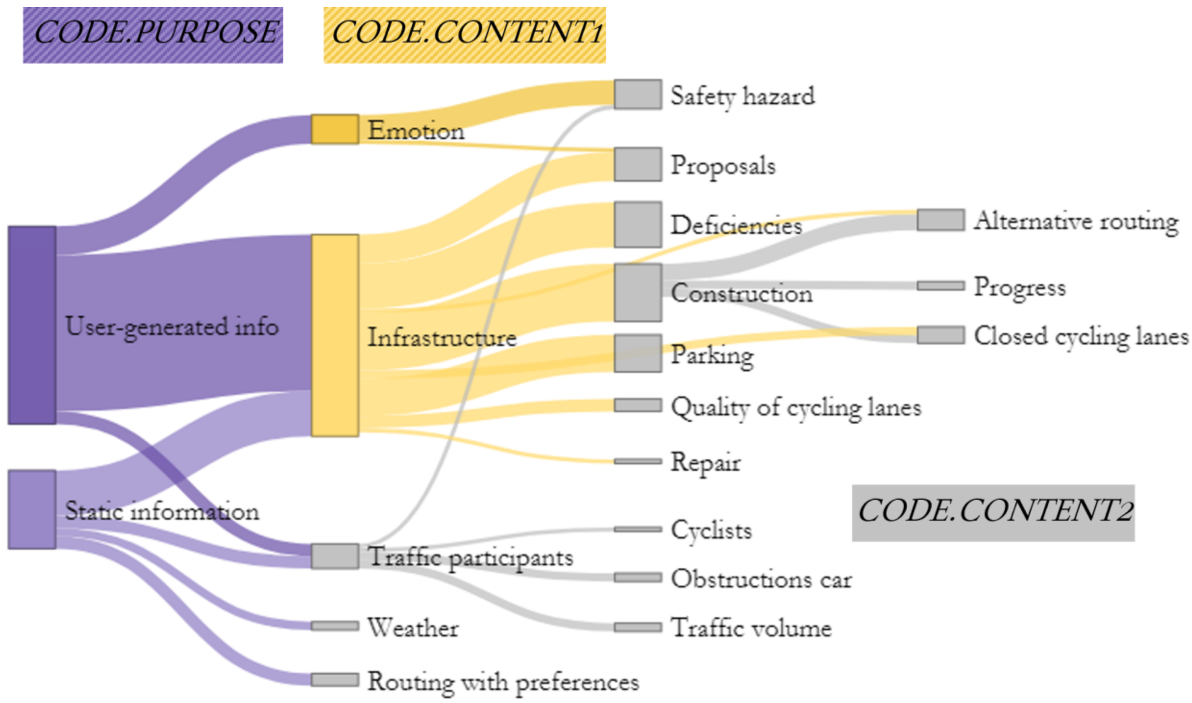


Figure 10: Flow chart of content-related codes from the open suggestions

Figure 10 visualizes derived codes from these open suggestions that are content-related (66 out of 80). The flow chart presents the codes from the usage purposes (*CODE.PURPOSE*) on the left over the categories of cycling emotions and cycling infrastructure (*CODE.CONTENT1*) to the more specific content suggestions on the right and the bottom (*CODE.CONTENT2*). The heights of the different bars reflect the count of code appearance within all open suggestions. Such a visualization is not appropriate to derive priorities of information or functionalities. It rather marks the possible functionalities and content of an urban cycling dashboard. Additionally, the flows between the code categories show adjacent relations between source code and target code but cannot be tracked over multiple code categories.

Figure 10 shows that most open suggestions are made in the context of an exchange of user-generated information about cycling infrastructure. This usage purpose of exchanging information between CC and DM is also mentioned together with information on cycling

emotions and on traffic participants (e.g. obstructions by cars). The other usage purpose of informing about static information is mostly related to cycling infrastructure or to more specific aspects such as information on traffic participants (e.g. traffic volume), weather or cycling routes. Within the most frequently addressed category of cycling infrastructure the survey participants (from the perspective of CC) suggest reporting deficiencies (e.g. shortcomings of cycling lanes), making infrastructural proposals, or receiving information about current constructions or future projects from the municipality. Additionally, more static information as on parking options or repair stations is also requested. Within the category of cycling emotions, the survey participants nearly exclusively want to exchange information on safety hazards (e.g. hotspots of hazards or collisions). This also confirms the highest priority of the safety subfactor that we detect previously.
Summarizing the open suggestions, we will account for the following aspects in the urban cycling dashboard. The focus on cycling infrastructure is confirmed by the open suggestions, as well as the outstanding priority of safety within the cycling emotions. Besides information on single cycling infrastructural components (e.g. parking options), especially the exchange of information between the user groups on cycling infrastructure (e.g. deficiencies, constructions, or proposals) is highly requested.

Modules and functionalities of the urban cycling dashboard
We now summarize the previous results to shape the content of the urban cycling dashboard that generally determines its utility for the users and eventually the value that it can provide for a city's cycling system (Young and Kitchin 2020). We structure the content of the urban cycling dashboard in modules as compositions of single functionalities.

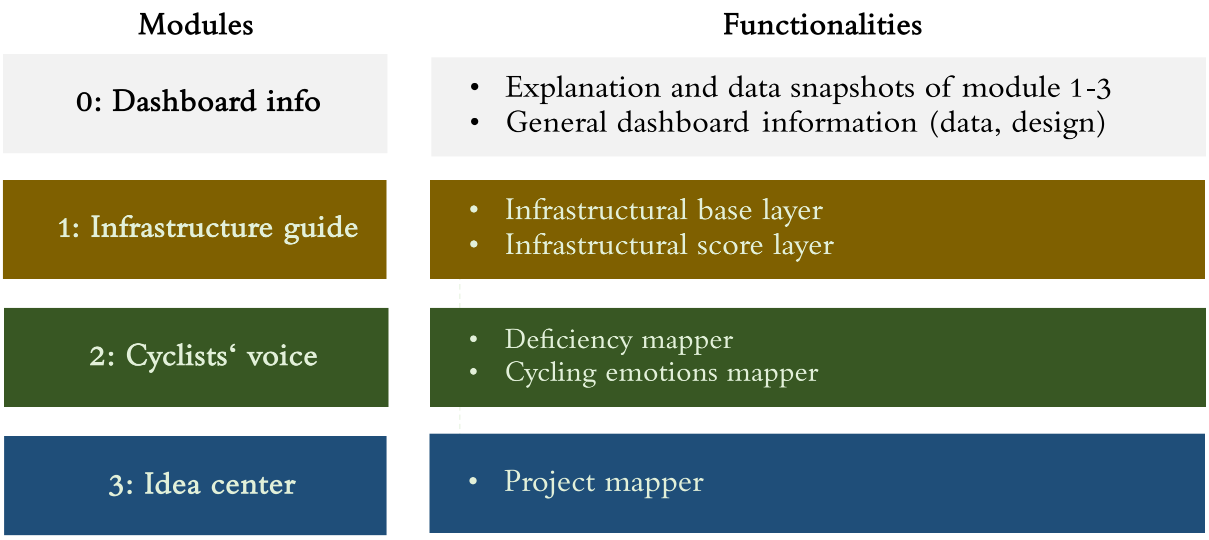


Figure 11: Modules and functionalities of the urban cycling dashboard

Figure 11 shows the structured content of the urban cycling dashboard with its four modules and the corresponding functionalities Module 0 is a general dashboard info page. Module 1-3 (infrastructure guide, cyclists' voice, idea center) are the core modules of the urban cycling dashboard and each provides at least one interactive functionality for its users. Although in general the modules and even their functionalities are independent of each other, a complete consideration of all four modules is recommended. Subsequently we will further explain each module more in detail.

Dashboard info

The central aim of the dashboard info page is to give general information about the urban cycling dashboard and to clearly communicate the structure of the dashboard with its three main modules and their respective objectives and capabilities. For the first module of the infrastructure guide this includes links to the cycling infrastructural data sources (e.g. OSM and municipal data portals), clear explanations of the cycling infrastructural subfactors that are used as indicators, and an explanation of their automated assessment. As the second (cyclists' voice) and the third module (idea center) are both participatory, the dashboard info page should clearly communicate the role of each user group here (CC or DM) and what they can expect from each other. As the dashboard info module can also be used as the landing page, first data snapshots from the different modules can be included here as well (Young and Kitchin 2020).

An additional objective of the dashboard info page is also presenting general information. Here, the results of the conducted user surveys can be presented (FixMyCity GmbH 2022), that explains the design of the urban cycling dashboard. Furthermore, as the urban cycling dashboard should be built on open source software, links to the source code should be given here as well.

Infrastructure guide

The first core module, the infrastructure guide aims at informing about and assessing the physical cycling infrastructure. This includes the two functionalities of the infrastructural base layer and the infrastructural score layer. The infrastructural base layer gives a general overview of the existing physical cycling infrastructure. It visualizes spatial data on a city's cycling infrastructure from OSM categorized by the seven cycling infrastructural subfactors (Fermazin 2021). Additional information on current road works that affect cycling or on cyclists' traffic volume (e.g. counting stations (Smart City Münster 2021a)) can be presented here as well. The infrastructural score layer automatically assesses the seven cycling infrastructural subfactors and calculates corresponding indicators as well as one common total score about the sustainability of urban cycling in different areas of one city. As the indicators and the final score are measured for areas we recommend resorting to existing administrative urban areas.

Cyclists' voice

The second main module, the cyclists' voice, is a participatory module for the user group of CC to generate data. Here, the participation of CC is split into the two interactive

mapping functionalities of a deficiency mapper and a cycling emotions mapper. Within the deficiency mapper, CC can map spatial objects of current and short-term deficiencies, that can be repaired without additional planning. The deficiencies must be provided with one main category and are supplemented with a subcategory, a textual description, a date with time and optionally a photo (Wenzel 2018). Possible main categories are lane surface (subcategories: e.g. ground material, obstructing objects, lane marking), traffic lights, wayfinding signs, parking options, and repair facilities. We highly recommend here that the spatial points are snapped to existing cycling infrastructure (Pánek and Benediktsson 2017), and therefore have a direct topology that cannot be misunderstood by the DM. Part of the deficiency mapper is also a reaction from the DM on the reported deficiencies, which is an important difference to the cycling emotions mapper. Therefore, the DM can tag and update the processing status of every deficiency (e.g. noted, planned, solved, postponed).
The cycling emotions mapper generally aims at capturing cyclists' experiences in a spatial data format. This information can be respected by DM to prioritize and plan future actions, but no data related reaction to single entries can be given. We suggest coupling the cycling emotions mapper to the coarse categories of cycling infrastructure and their corresponding spatial geometries: Lines for on-cycling infrastructure, points for parking, and points for cycling services. Here, every object is mapped with a positive or negative experience (Pánek and Benediktsson 2017; Snizek et al. 2013) related to one of the three most important cycling emotions of safety (Nelson et al. 2015), fast commute, and comfort. We neglect the least important emotions of happiness and relaxation as they are considered as fuzzy and too general. Additionally, CC can add a date with time to the mapped emotion and can optionally write a textual description to it.

Idea center

The third core module, the idea center, is a participatory mapper for the DM to communicate their future projects for a city's cycling system. Here, DM can publish spatially referenced projects with overview information (e.g. responsible city department, objectives), and an up-to-date progress (e.g. in concept, in planning, in construction, or finished) (FixMyCity GmbH 2022). When projects are in status of concept, DM can ask CC to comment textually or give map-based suggestions (e.g. parking racks). When projects are finished, CC can like the implementation as feedback for DM.

Potential extensions could be real-time information on recent and forecasted weather (Brocza and Kollarits 2020), or a routing functionality, that is frequently requested by CC. This routing functionality should respect real-time data as current constructions, give information on multi-modal use of transports, and include the selection of preferences. However, these extensions will not be addressed in the following chapters.

4.4.2 Architecture

In general we recommend to solely rely on open-source data and open-source technologies for the architectural set-up of the urban cycling dashboard (e.g FixMyCity GmbH (2022), or Smart City Münster (2021a)). Additionally, in our work the urban cycling dashboard is conceptually developed for a use on desktops rather than mobile devices. However, as the selection of the end device is influenced by the users (Young et al. 2021) and their functionalities (e.g. DM at work station) further developments of a mobile app are suggested with a focus on the participatory module 2, the cyclists' voice. Hereby, CC could directly map their cycling emotions or experienced deficiencies right after a trip.

The following outline of a conceptual architecture for our urban cycling dashboard mainly follows the review on geospatial dashboards by Jing et al. (2019) and the conceptual development of the Austrian bicycle observatory dashboard (Brocza and Kollarits 2020; Leitinger et al. 2020; Loidl et al. 2020).It is supplemented by survey insights from the open suggestions and inspiration from the dashboard review. Additionally, we resort the cooperative bachelor thesis for the data analysis method that proposes an automated assessment of cycling sustainability by Fermazin (2021). Subsequently, we will first introduce our three-tier architecture to finally close this section with more general recommendations on the scalability, interoperability, and portability of our architecture.

The three-tier architecture of data, methods, and presentation layers

Following a geospatial urban dashboard review by Jing et al. (2019) the most common architecture is three-tiered with a) a data layer (databases, data modelling), b) a methods' layer (automated and optional analyzes), and c) a presentation layer (e.g. GUI with interactive visualizations and mapping tools). Figure 12 (p. 45) illustrates a conceptual three-tiered architecture for our urban cycling dashboard. For the data layer, static data from OSM and other urban open data portals are used form external data storages. Additionally, an internal data base for the urban cycling dashboard stores the results from the method tier and the user-generated data as well as predefines their data modelling. The data modelling for the user generated objects of deficiencies, emotions, and projects will be exemplary presented in figures 13-15 (p. 48-50).

Table 2: Weighted subfactors and their respective indicators

Subfactor	Indicator	Mean weight
Traffic adaptions for cyclists	I1	22.10%
Cycling network	I2	20.60%
Priority of cycling	I3	18.45%
Accessible parking options	I4	13.85%
Quality of parking	I5	10.15%
Wayfinding systems	I6	9.20%
Repair stations	I7	5.65%

Within the method tier, the core is the automated sustainability assessment that is fed by OSM data (Fermazin 2021). Within this automated assessment, seven

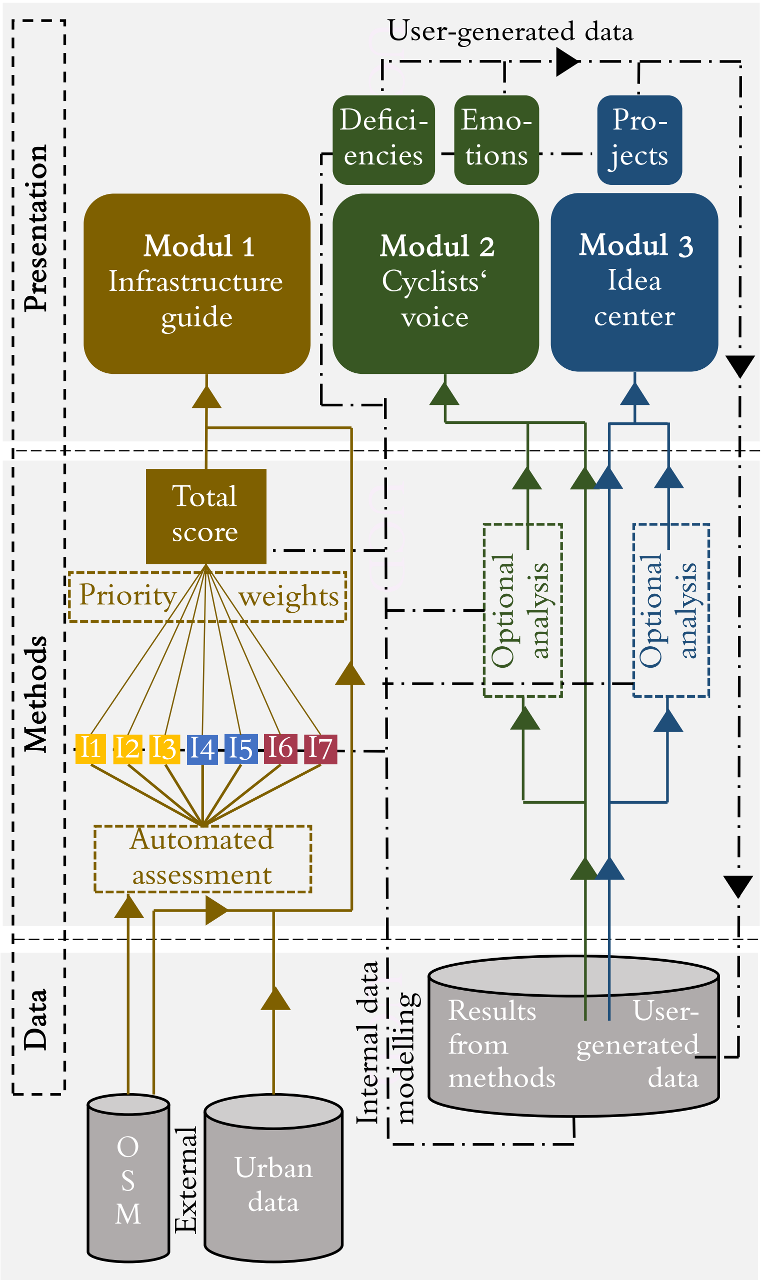


Figure 12: Possible three-tier architecture of the urban cycling dashboard

indicators representing the seven cycling infrastructural subfactors are calculated. To obtain the total score for one area, the seven indicators are overlaid by the weights of the respective mean priorities (table 2, p. 44). Additionally, optional analysis on the user-generated data can be performed (more in result section 4.4.3 on data visualization, p48-50).

Within the presentation tier, objects from the various data sources are visualized directly as single features (e.g. emotions, deficiencies, cycling infra-structure) or within statistically summarized graphics. Here, also the results from the method layer are presented, supplemented by the inter-active mapping tools allowing users to generate data.

When allowing interactive mapping, data visualizations, and selections of analysis, a tight coupling between all three tiers must be ensured, where each tier is dependent on both others (Jing et al. 2019). For different ways of technically connecting these tiers to guarantee respective data accesses and flows, we refer to Jing et. al (2019). Besides this three-tier structure, scalability, interoperability (Brocza and Kollarits 2020; Jing et al. 2019), and portability (Jing et al. 2019) of the architecture should be guaranteed.

Scalability, interoperability, and portability of the architecture

A scalable architecture allows the adding and removing of functionalities or data. This is an important requirement, as no single recipe exists for a locally adapted urban cycling

dashboard, and further internal evolution or shortenings should be possible (Brocza and Kollarits 2020; Jing et al. 2019). As our conceptual content and architecture is separated into three independent modules it is considered as scalable.
A proper interoperability of an architecture (Brocza and Kollarits 2020; Jing et al. 2019) ensures dealing with heterogenous data (e.g. spatiotemporal data from different sources) and heterogenous users. Here, we suggest to implement a personalization with profiles and roles (Brocza and Kollarits 2020; Jing et al. 2019) that is also requested by CC in the open suggestions (*CODE.SPECIFIC*). Besides possible content-related personalization (e.g. notifications on new constructions or planning projects within preferrable neighborhoods), specific actions can only be executed by different roles or profiles (e.g. DM: changing the processing status of a deficiency, or CC: comment on a planning project). Such data rights should be recorded in a data management plan (Brocza and Kollarits 2020; Leitinger et al. 2020). As a profile should not be mandatory, we suggest a default guest role that activates all CC-related actions excluding their personal reaction function in the idea center.
Furthermore, the portability of an architecture (Jing et al. 2019) provides access to all the data that is available and stored in the urban cycling dashboard. In general, this can be realized via application programming interfaces (APIs). For the external data sources, links are shared to the respective open data portals or APIs (e.g. overpass turbo for accessing OSM data). For the internal database an API could provide access to the analysis results and the user generated data (FixMyCity GmbH 2022).

4.4.3 Data visualization

The following guidelines on data visualizations are based on results from our literature and dashboard review 2. Therefore, we will 1) present these findings on data visualization of general urban dashboards, 2) relate them to our urban cycling dashboard, and 3) finally present guidelines on the data visualizations for our three core modules 1-3.

Data visualization on general urban dashboards

Data visualization is the essential part of an urban dashboard that distinguishes it from other mere open data portals. An urban dashboard’s goal is enabling personal knowledge building for its various types of users, by utilizing approaches of visual analytics including interactive and dynamic visualizations. Therefore, it explains and exhibits data and allows for own exploration, so that different types of users with different skills and motivations can extract knowledge that has a tangible outcome for their daily life (e.g. cyclists for their daily commuting, urban planners for their work) (Kitchin and McArdle 2017; Young and Kitchin 2020). A well-chosen selection and set-up of visualizations that is made available for users, determines not only the usability of a dashboard, but also the general data utility. Here, the most common visualization techniques that are presented on urban dashboards are graphics (e.g. from bar charts, and graphs to traffic lights, gauges), maps, and texts with images (Jing et al. 2019; Young et al. 2021; Young and Kitchin 2020). Graphics are used to allow a more intuitive and simplified access to numerical data. But they must be well designed regarding its aesthetics (e.g. pureness of graphics), perceptions (e.g. shapes or colors), and interactions (e.g. filters) to guarantee its comprehensibility and avoid misunderstandings (Healy 2018). Special attention is often paid to the use of interactive maps as the activation of simpler (e.g. panning or zooming) and more advanced interactions (e.g. overlays) must be considered carefully (Roth 2013; Young and Kitchin 2020). However, in regard to graphics and maps, it is recommended to present its metadata and add extended functionalities as printing, sharing, and personalized bookmarking that in general increases the data utility (Brocza and Kollarits 2020). Furthermore, texts can not only be deployed to reproduce textual data, but it can be used together with interactive graphics to form data stories, that especially gives novice users comprehensible insights (Young et al. 2021).

Geospatial data visualization in the urban cycling dashboard

However, the suitability of different data visualizations is also influenced by the underlaying data and its intended usage (Young and Kitchin 2020). Here, Marzouki et al. (2017) highlight the importance of geovisualization of data within participative processes that integrate citizens into urban planning. They argue that geovisualization is a common language that allows both sides, the citizens and decision makers, to easier understand the utility of data as it is presented in a known geographical environment (Marzouki et al. 2017). This is also important for the urban cycling dashboard as one of its focuses is to foster easy and digital citizen participation in urban cycling. As additionally all its underlaying data is georeferenced (static OSM data and user-generated data) we recommend utilizing map-centered visualizations for the modules 1-3 (infrastructure guide, cyclists' voice, idea center). These map-centered visualizations are supplemented by adding graphics on top, to present statistical summaries and therefore generate deeper insights into the data. As we utilize maps as the background and not as a parallel visualization medium, we advise against using multiple coordinated views that are commonly used for passively filtering data for graphics by the current spatial extent of a map (Jing et al. 2019). We rather recommend giving the users the active choice of filtering the data by its dimensions (location and date and time) or attributes.

Following these guidelines from the literature on general urban cycling dashboards, we suggest the following possible data visualizations for each module in figure 13-15 (p. 48-50). In addition, the figures13-15 also show the modules' underlaying data, its corresponding data sources, and data modelling. In the figures we subsequently use purple color to signalize interactivity (e.g. filters or optional analysis) and green for intermediate or resulting visualization media.

Data visualization for the first module: Infrastructure guide

Figure 13 shows the suggested interactive data visualization for module 1 the infrastructure guide. Here, the original data are spatial objects on cycling infrastructure from OSM. Besides their spatial geometry and further own attributes, each object is assigned to one of the seven cycling infrastructural indicators.

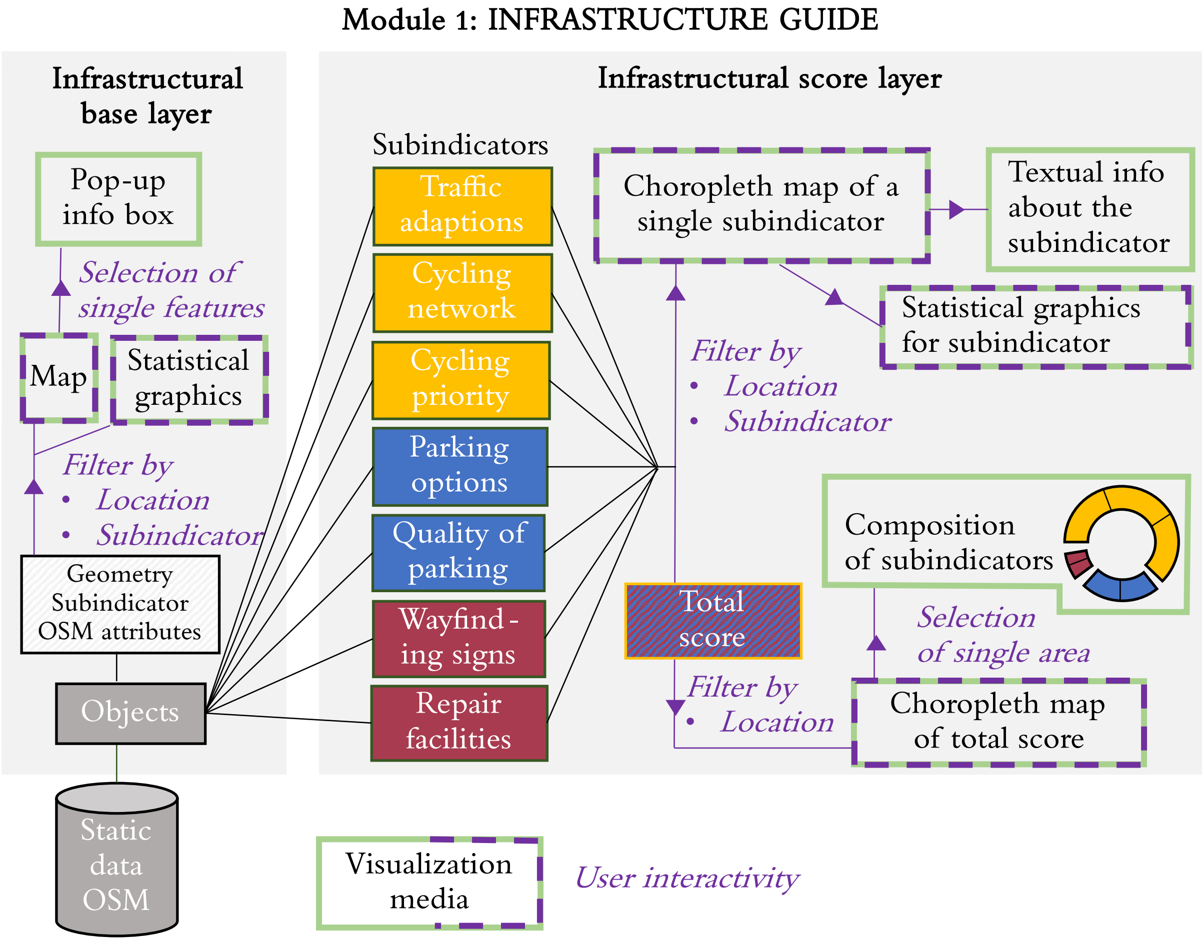


Figure 13: Data visualization for module 1: Infrastructure guide

The first functionality is the infrastructural base layer which communicates information about these original objects without any processing. The objects can interactively be filtered by locations (e.g. administrative areas) or their corresponding subfactors. This results in a selection of objects that are visualized on a map with different symbology. Additionally, interactive summary statistics on this data selection are shown on a graphic aside (e.g. amount of parking racks, summed lengths of cycling streets). On the interactive map users can select single features to get its detailed information in a pop-up info box (e.g. ground material of cycling lane, quality of parking rack, available tools at a repair station).

Within the second functionality, the infrastructural score layer, the seven indicators and their common total score are visualized. The users can filter for a specific indicator and locations to get a resulting choropleth map. Here, additional information on the respective indicator is provided as well as corresponding statistics (e.g. best three areas of that indicator). Additionally, the total score can be filtered by locations and is also visualized on a choropleth map. Here, a single area can be selected to receive further graphical information on the composition of the total score by its indicators.

Data visualization for the second module: Cyclist' voice

Figure 14 shows the suggested interactive data visualization for module 2, the cyclists' voice. Here, the original data is mapped participatively by the CC as spatial objects of cycling emotions and deficiencies in cycling infrastructure.

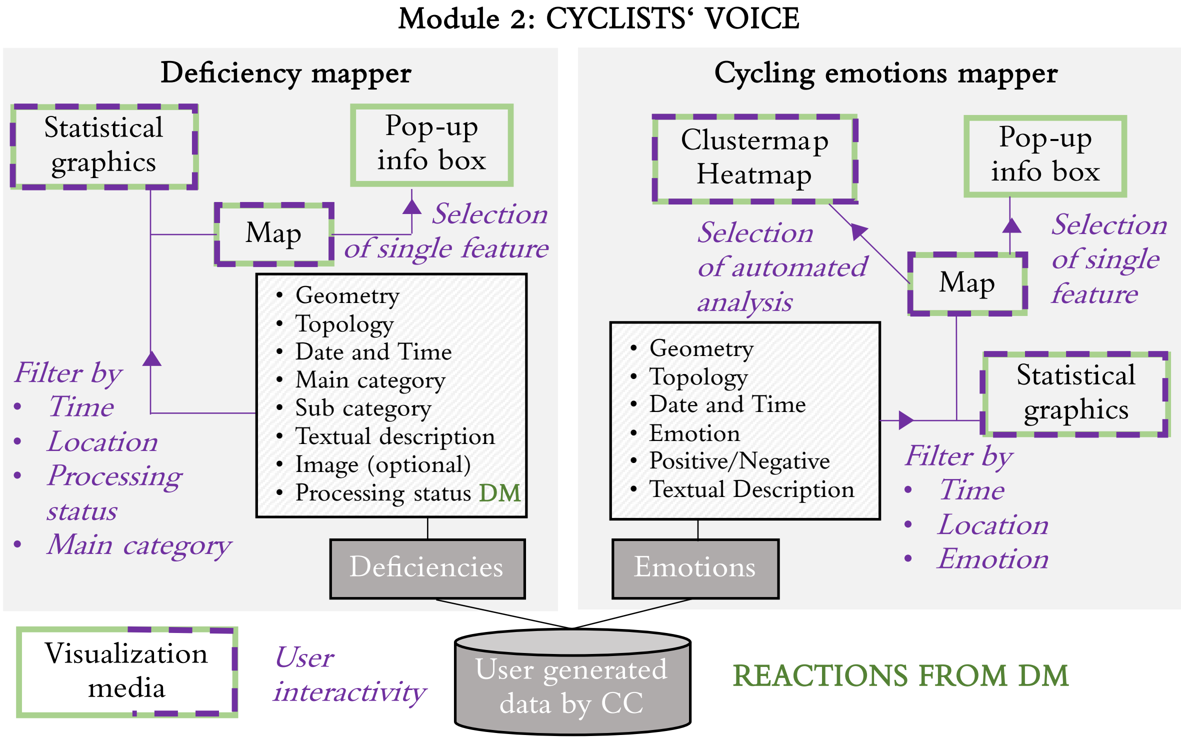


Figure 14: Data visualization for module 2: Cyclists' voice

The goal of the data visualization for the first functionality, the deficiency mapper, is to effectively give an overview of the mapped deficiencies of cycling infrastructure. Here, the deficiencies can be filtered by location, time, the processing status (reaction by DM), and the main category. Subsequently, the selection of filtered single objects is visualized on a map and corresponding statistical interactive graphics can give deeper insights (e.g. number of deficiencies per main category within a certain period). On the interactive map the users can select single features to get more detailed information in a pop-up info box (e.g. photo, textual descriptions, and other attributes).

The cycling emotions mapper aims in visualizing and analyzing the cycling emotions that are mapped by the CC. The users can filter these spatial objects by location, time, and the respective emotions (safety, fastness, comfort). The filtered emotions are statistically summarized in graphics aside and visualized as single features on an interactive map, symbolized by the emotion and its negative or positive expression. On this interactive map the users can again further select single emotional objects to receive detailed information on its attributes (e.g. date and time, textual descriptions). Additionally, the users can optionally select an automated analysis, such as spatial clustering or a point patter analysis to process the single emotions into aggregated information. The results are shown either on a clustermap or a heatmap (Nelson 2021).

Data visualization for the third module: Idea center

Figure 15 shows the suggested interactive data visualization for module 3, the idea center. Here, the original data is mapped participatively by the DM. The aim of the idea center is providing DM a platform for communicating their future projects and get feedback from the CC. The projects can be filtered by location and the progress status that is coupled with a date and time. The selection of filtered projects is visualized on an interactive map and corresponding statistical graphics aside (e.g. number of finished projects within a period). On the interactive map the users can select single projects to receive more details within a pop-up info box (e.g. image, objectives of the project). Additionally, here the DM can select a method to analyze the feedback that was given by CC. This can be a textual mining method for comments or heatmaps for spatial suggestions (e.g. on location of parking racks). The results are presented either in a graphic aside or on the map.

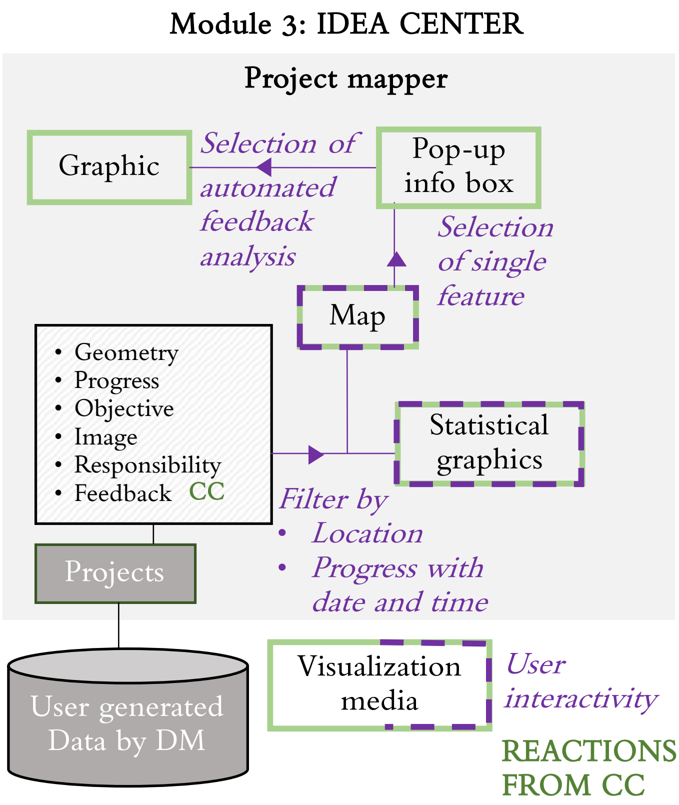


Figure 15: Data visualization for module 3: Idea center

4.4.4 Web design

After elaborating guidelines on content, architecture, and data visualization, we will now outline guidelines for the last structural component of web design. Therefore, we start with presenting web design aspects of general urban dashboards that we find in the literature and dashboard review 2. Subsequently, we will relate those to our urban cycling dashboard.

Web design of general urban dashboards

The web design of an urban dashboard determines its usability by providing an effective, intuitive, and enjoyable user experience (Brocza and Kollarits 2020; Young and Kitchin 2020). This encompasses a) the visual aesthetics and interface style (Kitchin and McArdle

2017; Young and Kitchin 2020), b) a clear navigation through the structure of the dashboard, and c) the arrangement or layout of single visual components on a web page (Jing et al. 2019; Young and Kitchin 2020).

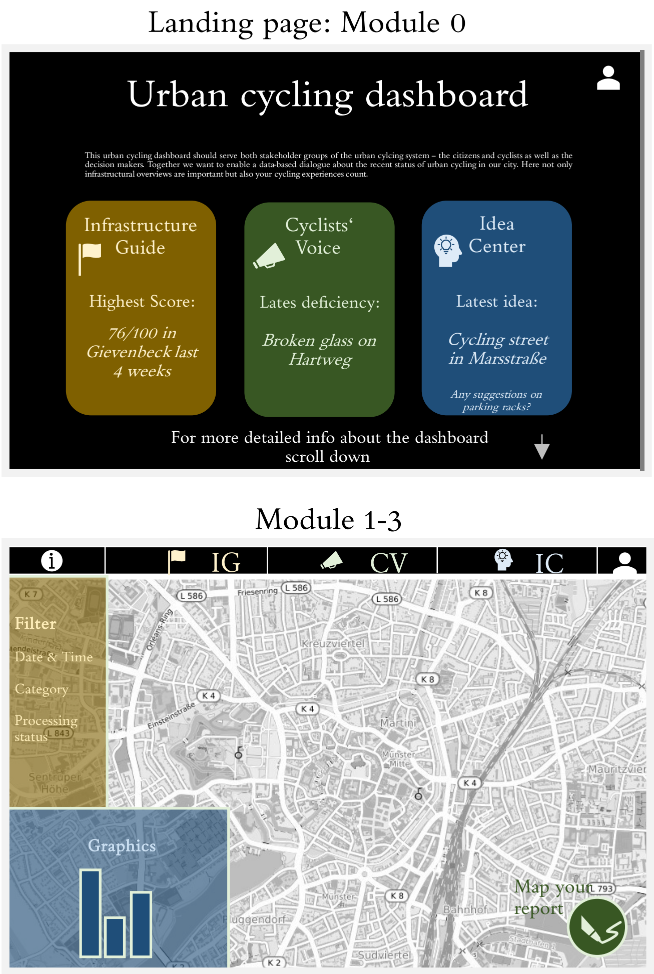
In developing the style of urban dashboards, a well-designed interface with nice visual aesthetics is often neglected (Kitchin and McArdle 2017). However, the resulting look-and-feel of an urban dashboard is evident to have a significant impact on the user enjoyment and motivation (Young and Kitchin 2020). It is not in the scope of this work to outline general web design principles for interactive virtual interfaces. Therefore, we merely refer to the usability study of urban dashboards by Young and Kitchin (2020) and recommend a coherent style over all dashboard pages, as well as the use of predesigned and recognizable graphics as theme icons.

Additionally, an easy navigation within a clear content-related structure of an urban dashboard is essential in ensuring an intuitive and effective usage. Here, a clear information architecture such as a hierarchical structure of tiles (Brocza and Kollarits 2020) can enable fast and interesting insights with few clicks. Also the landing page is identified as a crucial consideration. It can increase the usability by helpful explanations and it can trigger curiosity when it directly displays quick views on some data (Young and Kitchin 2020). The general navigation through an urban dashboard is mainly influenced by the website setup that can vary between single one pages, drilldown pages, or multiple pages. However, it is always dependent on the underlaying data, indicators and content (Jing et al. 2019; Young and Kitchin 2020). In more advanced web designs of urban dashboards Young et al. (2021) present design patterns as navigation paths for different levels of users ranging from explanatory data stories for novices, to exhibitory queries, and up to exploratory tools for experts. However, such an advanced web design is out of the scope for our urban cycling dashboard.

Furthermore the final screen layout of an urban dashboard deals with the simultaneous arrangement of the single visual components at one screen (Jing et al. 2019; Young and Kitchin 2020). Regarding geospatial urban dashboards, the map is one central visual component that can be integrated as a background or on the same level next to other graphics. Additionally, other visual components that are considered in the layout are commonly menus, and filters (Jing et al. 2019).

Web design of the urban cycling dashboard

Following these web design guidelines on general urban dashboards, we suggest a multi-page structure for our urban cycling dashboard. Here, each page should contain one of the four modules, that are also used as a navigation menu. Figure 16 (p. 52) shows the layout of module 0, the dashboard info, and an exemplary layout for the core modules 1-3. Module 0, the dashboard info, is designed as a drilldown page. Module 0 is laid out as the landing page and besides text for general information the center visual elements are three boxes



with freshest data insights from the three core modules 1-3. The single layouts of the remaining three core modules are designed in a similar way. The map is the central background, where at the left edge user can choose between various filters and see the resulting graphics in the left lower corner. On the right corner a button for the user participation is provided, where they can switch to a data generating tool for module 2 and 3. The navigation between all the modules is ensured by a headline menu that contains predesigned module icons.

Figure 16: Structure and layout of the urban cycling dashboard

5 Discussion

The discussion serves as critical reflection of the used methodologies and as interpretation of the results, also including limitations and challenges. Additional to findings from the literature review, two expert interviews with the municipality of Münster - cycling office (Fahrradbüro Münster 2022) and smart city department (Smart City Münster 2022) as well as one focus group meeting with a cycling advocacy club (IG Fahrradstadt Münster e.V. 2021) were conducted based on a presentation of preliminary results. The discussion chapter will 1) critically reflect the used methodology, 2) discuss and interpretate the categorization and prioritization of cycling infrastructure and emotions, 3) outline limitations of the recommended content and architecture, 4) highlight potential usage conflicts, and 5) discuss the user-centric design of the urban cycling dashboard in Münster. Last, the locality of our findings are underlined while relating potentials of our study to other cities and their urban cycling systems.

5.1 Methodology

In this subchapter we critically reflect the used methodologies starting with 1) a discussion of both literature and dashboard reviews, and 2) closing with limitations of the conducted user survey.

5.1.1 Literature and dashboard reviews

Both literature reviews are non-systematic reviews as no concrete sampling or selection methodology of literature was applied. Although the sampling criteria are described in the corresponding methodology sections and the papers were found via snowball sampling, the final selection of papers is subjective. Regarding the reviewed dashboards and platforms on urban cycling, we focused on applications in German. However, this review is also not systematic and serves more as an inspiration for possible and applicable functionalities.

5.1.2 User survey

Web-surveys give the advantage of collecting both quantitative and qualitative data from a bigger population (Lazar 2017). We will critically reflect these two data collections and additionally discuss the reliability and representativeness of the conducted survey.

Quantitative tasks

While quantitative data enables statistical analysis to easily aggregate the responds, these statistical results only provide shallow and non-explained information. Especially in the context of unsupervised surveys where no direct communication between the researcher and the participant is possible, quantitative tasks are prone to misunderstandings or miss-estimations. This concerns not only the prioritization tasks (tasks 1-3) that can easily feel repetitive, but also the estimation of single usage motivations (task 4) between 0 and 100 without any numerical examples for orientation or reference. Therefore, the resulting motivations are hardly comparable between the respondents, which is also shown in the high statistical variations for both user groups (see boxplots in appendix E1 and E2, p. 86).

Qualitative tasks

We set one qualitative task of freely mentioning open suggestions (task 5) for an urban cycling dashboard. As this task was optional to be filled, we did not expect that more than one third (43 CC and two DM) came up with at least one suggestion. Although the participants were just briefly introduced into the theme of an urban cycling dashboard in the beginning of the survey, only four open suggestions out of 84 were clearly not related to the topic. Due to the open frame of this qualitative task participants could explain their concrete expectations. However, for a meaningful aggregation of the textual comments, each suggestion was labeled with several codes. Here, it is recommendable to apply a mixture of deductive and inductive coding that allows to relate findings to previous theories (deductive) but at the same time leave the open door for surprising new insights (inductive). These unexpected insights were eventually beneficial for the results of the survey and the conceptualized development of the dashboard (e.g. deficiency mapper).

Reliability and representativeness of the conducted survey

Regarding the reliability of the conducted survey, we can state that the participants in general responded with attention (figure 17) and interest (figure 18). However, nine participants expressed missing knowledge (figure 17), which confirms the challenge of distant web surveys that are not enough for properly integrating the user groups without misunderstandings. This also became evident by open comments on the survey.
However, the reliability of the statistical results (e.g. median of usage motivations) regarding the user group of decision makers is questionable as only eight of them responded.

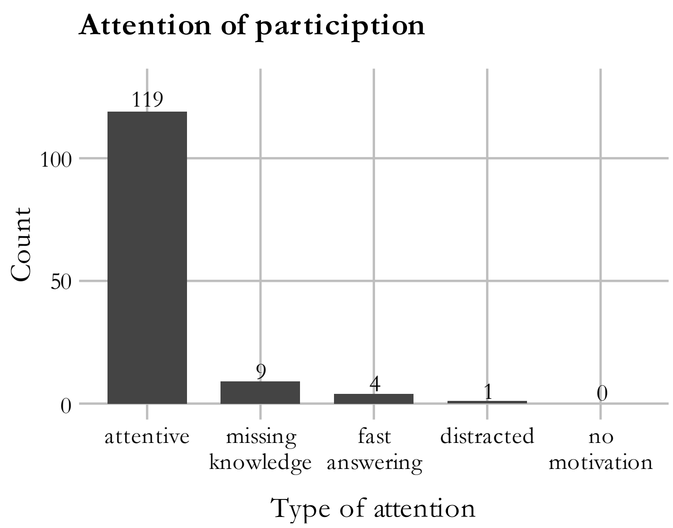


Figure 17: Attention of the survey participants

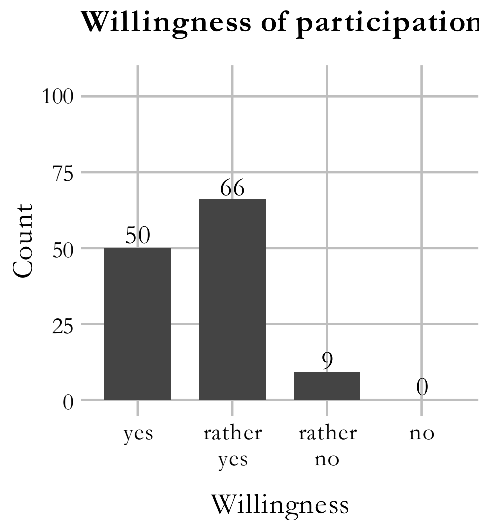


Figure 18: Willingness of the survey participants

Regarding the representativeness of the results, 125 participants cannot properly represent the targeted population of CC and DM in Münster. Additionally, as there are mostly young and high-frequent cyclists amongst the participants of the survey (figure 4 and 5, p. 35) we can consider that the results are biased (Fahrradbüro Münster 2022), but on a natural way. It makes sense that especially high-frequent cyclists with a strong interest on the urban cycling system are voluntary to participate in such a survey. Additionally, as this thesis is written in a university context, it is also reasonable that more young people participated. But this can also be influenced by the digital nature of the topic where young people might have more relation to. However, as people under 30 years are actually the biggest group of cyclists in Münster (Stadt Münster 2020a), our survey participants represent the population of CC in this matter.

5.2 Cycling infrastructure and cycling emotions

In this second subchapter we will discuss the definition of the two categories of cycling infrastructure and cycling emotions and their corresponding subfactors, that were prioritized within the user survey and contributed to design of the urban cycling dashboard. First, their semantic definition is discussed followed by an interpretation of their resulting priorities.

Definition of categories and subfactors

In general, respecting the novel category of cycling emotions next to the more common category of cycling infrastructure is considered beneficial for a sustainability assessment of urban cycling. Confirming our findings from the first literature review, the emotional experiences of cyclists are important subjective information that extend the rather unpersonal view of merely taking cycling infrastructure into account (Fahrradbüro Münster 2022). The respective subfactors for the categories of cycling infrastructure and cycling emotions are also reasonably chosen (Fahrradbüro Münster 2022). Especially the subdivision of cycling infrastructure into the main groups of linear on-cycling infrastructure, punctual parking infrastructures, and additional services provides a clear three-part structure (Fahrradbüro Münster 2022).

It is important to clearly communicate the demarcation between the subfactors within the respective category. For the cycling infrastructure this affects the understanding and interpretation of the scored indicators and the weighted total score. However, when dealing with cycling emotions, a distinctive explanation of the single emotional meanings is not only essential for a resulting understanding of this information but in an earlier stage also for allocating a cyclist's emotion while generating experience-based data in the cycling emotions mapper (in module 2, cyclists' voice).

Priorities of cycling infrastructure and cycling emotions

The resulting priorities highlight the importance of cycling infrastructure in comparison to cycling emotions. However, cycling infrastructure is naturally more tangible than cycling emotions since cyclists directly experience different infrastructure but not consciously perceive cycling emotions. As cycling emotions are also a new field, not in research but in operational cycling planning, a certain shyness towards this novel category could also affect its lower prioritization (Fahrradbüro Münster 2022).

Regarding the single prioritized subfactors within the category of cycling infrastructure, the most striking difference between CC and DM was detected for the subfactors of cycling priority and the cycling network. While for CC cycling priority was the second most important subfactor and the cycling network the third, for DM it was the other way around. Here, urban transportation planners that participated as DM have a more holistic perspective of the traffic system and therefore tend to a more balanced assertion regarding the cycling priority (e.g. also taking public transport or pedestrians into account). In contrast, the survey group of CC represents high-frequent cyclists that are therefore biased to clearly advocate a cycling priority (e.g. often see cycling in the comparison only to motorized vehicles) (Fahrradbüro Münster 2022). Furthermore, the ranked priorities of cycling emotions can be reasoned by experts, who especially highlight the importance of perceived safety for cyclists, but also for non-cyclists as a major impedance (Fahrradbüro Münster 2022; Manton et al. 2016; Nelson et al. 2015; Snizek et al. 2013).

5.3 Content and architecture

The general structure of the urban cycling dashboard is reasonable from the perspective of our two expert interview partners (Fahrradbüro Münster 2022; Smart City Münster 2022). Interestingly, the presented functionalities show similarities to already other existing tools (FixMyCity GmbH 2022; Nelson 2021). The urban cycling dashboard as a central platform with its different modules and functionalities also delivers a clearer picture of the already existing digital offers and tools in Münster spread over different web pages (Fahrradbüro Münster 2022; IG Fahrradstadt Münster e.V. 2021). Simultaneously, the more modules and functionalities are included in the urban cycling dashboard the higher the complexity of usage (Fahrradbüro Münster 2022). Subsequently, we will discuss challenges and further potentials regarding the three central modules and their functionalities. This subchapter will be closed with remarks on the architectural guidelines.

Module 1: Infrastructure guide

Within the module of the infrastructure guide, the first functionality of the infrastructural base layer is generally a desired functionality as no such a transparent digital overview of the physical cycling infrastructure exists so far in Münster (Fahrradbüro Münster 2022; IG Fahrradstadt Münster e.V. 2021). Besides the infrastructural data from OSM, posting data on current constructions that affect cycling is challenging for the DM. As too many different private or municipal actors are involved here, an internally structured data management is needed first (Smart City Münster 2022). The second functionality of the infrastructure score layer could provide an interesting overview of the cycling infrastructure's quality for DM (Fahrradbüro Münster 2022). However, no data on wayfinding signs are available on OSM and therefore the sixth indicator for the wayfinding system cannot be automatically calculated (Fermazin 2021). Additionally, a comparison between the total scores from different assessed areas is questionable as different demands for cycling infrastructure (e.g. higher in the city center than in rural districts) is not considered in the calculation (Fahrradbüro Münster 2022). Additionally, the indicators and the resulting total score will show low temporal changes as it is dependent on updates of the infrastructural data on OSM. This will neither satisfy the need of urban transportation planners on more temporal insights of cycling (Loidl et al. 2020), nor will it motivates users to revisit the urban cycling dashboard frequently (Brocza and Kollarits 2020; Kitchin and McArdle 2017). Therefore, as a major but complex improvement we suggest integrating the user-generated data from the module cyclists' voice (deficiency mapper and cycling experience mapper) into the assessment of cycling quality. As this data have a finer temporal granularity and show more frequent changes it could refine the temporal insights from the score. However, the actual integration of this data into the score triggers many questions, as how should it be weighted to the other factors, and over what time frame should it influence the score. Here also the development of better data visualization and analytical tools must be considered to guarantee a comprehensible final score.

Module 2: Cyclists' voice

Within the next module of cyclists' voice, it can be difficult for CC to clearly distinguish the purposes of the two provided functionalities, the deficiency mapper and the cycling emotions mapper. Here, when CC want to map their cycling experience they can have issues with distinctly allocating their contribution to only one functionality (Fahrradbüro Münster 2022; Smart City Münster 2022).

However, a simple deficiency mapper that is frequently requested by CC would provide desired and accurately georeferenced information for DM (Fahrradbüro Münster 2022). Here, its purpose must be clearly communicated and the interactive mapper must be intuitively and semantically designed in a way to ensure that only acute short-term deficiencies are mapped and no long-term ideas form CC are launched there, as they could not be processed by the DM. Additionally, a municipality must provide adequate internal structures so that information on deficiencies a further properly managed by the DM (e.g. forwarding a corresponding order for repairing, or reacting with a processing status on the dashboard) (Fahrradbüro Münster 2022; Smart City Münster 2022).

The second participatory functionality, the cycling emotions mapper, needs most further refinement. In general, it so far works as a crowdsourcing tool to collect data on cyclists' emotions rather than meaningfully integrate them into an assessment. As it therefore is not clearly advantageous for CC, the benefits of sharing their experienced emotions are important to be communicated. For example, the DM can relate their knowledge that they have gained from this functionality to current or future projects. Additionally, CC can also be encouraged to map their cycling emotions on their most common routes, where they have a stronger relation to (Marquart et al. 2020; Pánek and Benediktsson 2017; Snizek et al. 2013). In general, it is expected that especially negative cycling experiences are mapped by the CC although also positive ones would provide beneficial insights (Fahrradbüro Münster 2022). Besides appropriate visualization of this user-generated experiences, more investigation is necessary on how the urban cycling dashboard can provide analytical tools to ensure knowledge extraction based on that data.

Module 3: Idea center

Within the last participatory module, the idea center, a structured data management within the municipality is needed again to guarantee up-to-date information (Smart City Münster 2022). Additionally, a simple but more flexible mapping tool should be designed so that DM can easily publish and update their projects. Another challenge concerns the possible reactions on projects by CC (e.g. comments or likes). Here, the possibility of reacting should only be activated for CC if active feedback is desired by DM (e.g. location and amount of parking racks along a streetscape) (Fahrradbüro Münster 2022; IG Fahrradstadt Münster e.V. 2021; Smart City Münster 2022). In general a clear overview of the projects (e.g. by year, location, likes) is necessary to avoid an unstructured mass of single ones (FixMyCity GmbH 2022).

Guidelines on architecture

As the architecture is closely linked to the module-based structure, its guidelines will be briefly reflected subsequently. Regarding the data layer, parallel structures of external data between open-source data (e.g. OSM) and municipal data should be as reduced as possible (Smart City Münster 2022) and data should be technically modelled in consistent spatio-temporal formats (Jing et al. 2019; Loidl et al. 2020). Regarding the analysis layer, a good balance between leveraging updates of pre-calculated results (e.g. indicator scores) and on-demand calculations of optional analysis should be found.

In general the urban cycling dashboard should provide a fast responding interaction between the user, the device and the data processing in the background (Roth 2013). However, when providing a participatory dashboard with multidirectional data flows the back-and-forth communication between the three-tiers of data, analysis, and presentation becomes more complex (e.g. within the presentation layer the user can also generate data).

5.4 Usage conflicts

In general, the intended usage and capabilities of all three main modules with different functionalities are hard to mediate from the developers' perspective, and complex to understand from the users' view. Too many functionalities can easily cause confusion among the users (Fahrradbüro Münster 2022). Especially the participatory modules (cyclists' voice and idea center) need an intuitive handling and understanding to run properly and to guarantee a productive data-based dialogue between the two user groups. Therefore, we will subsequently discuss how this participative aspect is covered by the results from the usage motivation triangle (result chapter 4.3, p.35-36) and point out the importance of a proper expectation management.

Motivation gap between participatory usages

Although the DMs' motivation of generating information for the CC is ranked as the lowest within the usage motivation triangle, the municipality of Münster emphasizes that communicating information transparently is of high importance to them (Fahrradbüro Münster 2022). Assuming that the values of the usage motivations (figure 6, p. 36) depict real motivations of the user groups, it naturally makes sense that each user group is more motivated to receive information than to generate information (Smart City Münster 2022). Generating information always means more effort while working resources and capacities are limited for DM in municipalities or the dashboard usage is voluntary for CC (Fahrradbüro Münster 2022). Regarding the evident motivation gap between the participatory usages in the usage triangles (figure 6, p. 36), all interviews confirm that one of the biggest challenges of a successful participation within the urban cycling dashboard is a balanced exchange of information from and to both user groups. A dashboard that promises a participative exchange of information but only collects data from CC without any direct feedback, can end up in disappointment or frustration (Fahrradbüro Münster 2022; IG Fahrradstadt Münster e.V. 2021; Smart City Münster 2022). Here, a good example of a participatory platform that did not fulfill its expectations is a former deficiency reporter for cycling infrastructure in Münster, that was developed 2018 by the local green party (Wenzel 2018). Here, CC reported 376 infrastructural deficiencies with the expectation that they all get considered by the DM (IG Fahrradstadt Münster e.V. 2021). However, the DM were not integrated into the platform's design and therefore only reacted partly on a voluntary base. Therefore, the CC's expectations of the platform were disappointed and the platform could not realize its promises (IG Fahrradstadt Münster e.V. 2021).

Expectation management

To avoid such fails of participatory platforms, the users' expectations of its capabilities and their expectations towards other user groups must be managed and communicated clearly in advance (Fahrradbüro Münster 2022). This expectation management and communication should be an essential part of module 0, the dashboard info and help page. In our case the user survey showed that the participatory usage motivations do not match between the user groups so far as it lacks motivation to generate information. Therefore, the question arises on how to design participatory tools that highlight the benefits of creating information for other user groups. Only if the usage motivations and expectations match between the user groups, digital and permanent participation can fulfill its promised potential and does not turn into frustration (Fahrradbüro Münster 2022; Smart City Münster 2022).

5.5 User-centric design

In consensus with existing literature and with experts from the municipality of Münster, integrating the intended users at the earliest stage of an urban dashboard's development is essential. Only if urban dashboards contain the functionalities that are requested, they will be adapted and used by the stakeholders (Kitchin and McArdle 2017; Smart City Münster 2022) and will have an impact on the urban cycling system in our case (Fahrradbüro Münster 2022). In this subchapter we will therefore discuss our approaches of user-centric design during the conceptualization of the urban cycling dashboard. We will discuss 1) the definition of user groups, 2) our ways of user integration, and 3) closing with a critical reflection of the guidelines on visualization and web design.

Definition of user groups

When integrating future intended users into the development of an urban cycling dashboard, it must be considered that there is no uniform group of users as they approach the dashboard with different skills, expectations, and intentions (Young and Kitchin 2020). It is therefore necessary to split future intended users into user groups (Young et al. 2021). Brocza and Kollarits (2020) form various types of users for their bicycle observatory project: Five primary user groups of cycling-coordinators, political DM, transportation planners, cyclists, citizens' stakeholders, as well as four secondary groups of non-cyclists, interested citizens, press agents, and experts in public relations. However, we decided to form only two coarse user groups of CC and DM which enabled us to easily ask role-specific questions in the user survey and investigate digital participative processes within an urban cycling dashboard (Marquart et al. 2020). Simultaneously, it also tailors the urban cycling dashboard only to these two groups and therefore narrows down the initial openness for a general public use.

Methods of user integration

From our experience, we suggest that surveys can be a good initial step for an integration of the intended user groups, especially to capture the attitudes from a bigger user group (e.g. CC). They can also be used to prioritize a range of indicators (Sardain et al. 2016). However, we also recommend collecting more insightful qualitative data, either by improving or extending the open suggestion task or conducting other methodologies as focus group meetings, especially for the integration of smaller user groups (e.g. DM). In our first development phase of conceptualizing a potential urban cycling dashboard, we also further recommend creating design personas, that describe potential experiences, skills, expectations, preferences, or typical tasks of different representatives from each user group (Young et al. 2021).

Guidelines on data visualization and web design

Building user-centric guidelines without having a first implemented prototype of an urban cycling dashboard is not very robust (Young and Kitchin 2020). Especially for the guidelines on data visualization and web design, merely literature and existing urban dashboards were reviewed, which does not integrate the actual intended users. Here, more specific questions could have been asked in the survey.

Regarding the data visualization, further studies on the users' degree of freedom of interacting (e.g. filters) (Jing et al. 2019; Robinson 2017) or choosing between options of further automated analysis (e.g. heatmaps on cycling emotions) are recommended. Besides this, also the web design of the whole urban cycling dashboard needs deeper investigations. On the one hand, this includes the general structure and navigation through a complex urban cycling dashboard that provides different usages from assessments to participatory modules. On the other hand, the web design also implies the deployment of intuitive and efficient participatory tools which is essential for the motivation of users and the quality of the generated information (e.g. cycling emotions, or infrastructural deficiencies) (Pánek and Benediktsson 2017; Snizek et al. 2013). Such participatory mapping tools face common challenges such as the georeferencing of emotions or the importance of supporting base maps (Poplin 2017).

As user-centric design is an on-going process during the conceptualization, implementation, further advancements, and maintenance of urban dashboards, it needs redirections and reconsiderations during all further stages to guarantee the dashboard's usability and utility for its users (Young and Kitchin 2020).

5.6 Locality of findings

The presented and discussed guidelines for the participatory urban cycling dashboard are locally specific as we derive our results from a user survey (usage motivations, open suggestions, and prioritizations) that merely captures the personal attitudes of CC and DM from our case study in Münster. Therefore, we do not recommend following exactly the results from our survey in other cities, as the local community, knowledge and expectations must be integrated into the design of other local urban cycling dashboards. For example, already in our case the surveyed priorities of the cycling infrastructure indicators and the priorities that DGNB suggests for their automated sustainability assessment differed greatly.

However, our methodology of conducting a user survey can be respected for other conceptualizations of urban cycling dashboards. In a retrospective of our survey we suggest covering the following three aspects. First, asking for usage motivations can reveal a priori challenges of the participatory usage, that can in turn be counteracted from beginning (e.g. missing motivation to generate information in Münster). Second, open-framed questions allow for locally specific insights on special functionalities (e.g. deficiency mapper in Münster). Third, a local community's prioritization of the indicators from cycling infrastructure and cycling emotions tailors the assessment of the urban cycling system to its city.

6 Conclusion

In this work we present and discuss guidelines for a participatory urban cycling dashboard in Münster, Germany. In general, this conceptualized urban cycling dashboard collects, assesses, and visualizes cycling-related data on one central platform. Hereby, it enables a systematic approach of exploratory data analysis to better understand the spatiotemporal complexity of urban cycling. To ensure future usability and utility of a user-centered urban cycling dashboard, we conducted a user survey with the two groups of decision makers and citizens, cyclists. This survey revealed that users prefer an informational focus on cycling infrastructure, supplemented by information on cycling emotions. Here, the urban cycling dashboard integrates an automated sustainability assessment in the infrastructure guide module to spatially differentiate the quality of urban cycling within one city, based on data from OSM. To integrate the knowledge of the urban cycling community and approach a more user-centered assessment, the single indicators are weighted by the prioritization of the survey to form a total score. Additionally, the survey showed that participatory modules can support a motivating exchange of user generated information on infrastructure deficiencies and cycling emotions (module: cyclists' voice) or on collaboratively developing future projects for improvements of the urban cycling system (module: idea center).

Therefore, an urban cycling dashboard can support better understanding and greater transparency of the urban cycling system by integrating, assessing, and visualizing urban cycling data. Additionally, it can also foster digital and permanent exchange of information between the local decision makers and the cyclists by including participatory modules.

However, the urban cycling dashboard is so far only theoretically conceptualized, and an implementation is utopian to be realized at once. Therefore, while stepwise implementing such an urban cycling dashboard, GIS developers must refine or redirect the presented guidelines on the structural components while ideally having a constant feedback loop with researchers. Here, regarding the architectural set up, we suggest further research on analytical methodologies as the automated processing of the user-generated data as also its meaningful integration into the assessment score of the quality of urban cycling. Furthermore, for ensuring an intuitive and effective usage of the urban cycling dashboard we suggest to further conduct usability studies of prototypes to improve the web design and data visualizations as well as the participatory mapping tools. Finally, we suggest continuing this user-centric research beyond the dashboard's conceptualization, design, and development to investigate how the local community uses and engages with a deployed urban cycling dashboard to guarantee its tangible outcomes for the urban cycling system in a socially responsible manner.

Bibliography

Allaire, J. J., P. Ellis, C. Gandrud, K. Kuo, B. W. Lewis, J. Owen, K. Russell, J. Rogers, C. Sese, and C. J. Yetman. 2017. *networkD3: D3 JavaScript Network Graphs from R*. R.

Barrero, G. A., and A. Rodriguez-Valencia. 2021. "Asking the user: a perceptional approach for bicycle infrastructure design." *Int. J. Sustain. Transp.*, 1–17. https://doi.org/10.1080/15568318.2020.1871127.

Behrendt, F. 2020. "Mobility and data: cycling the utopian Internet of Things." *Mobilities*, 15 (1): 81–105. https://doi.org/10.1080/17450101.2019.1698763.

BMVI. 2021. *National Cycling Plan 3.0; Germany 2030 - a cyling nation*. 80. Bundesministerium für Verkehr und digital Infrastruktur.

Boschmann, E. E., and E. Cubbon. 2014. "Sketch Maps and Qualitative GIS: Using Cartographies of Individual Spatial Narratives in Geographic Research." *Prof. Geogr.*, 66 (2): 236–248. https://doi.org/10.1080/00330124.2013.781490.

Brocza, U., and S. Kollarits. 2020. "Dashboard Radverkehr: alles im Blick." *AGIT - J. Für Angew. Geoinformatik*, (6): 238–243.

Cho, F. 2019. *ahpsurvey: Analytic Hierarchy Process for Survey Data*. R.

Copenhagenize Design Company. 2022. "2019 Copenhagenize Index -." Accessed January 17, 2022. https://copenhagenizeindex.eu/.

DGNB. 2020. *DGNB System Kriterienkatalog Quartiere*. 551. Kommentierungsversion. Stuttgart: Deutsche Gesellschaft für nachhaltiges Bauen.

Dunn, C. E. 2007. "Participatory GIS — a people's GIS?" *Prog. Hum. Geogr.*, 31 (5): 616–637. https://doi.org/10.1177/0309132507081493.

Estevez, E., T. A. Pardo, and H. J. Scholl (Eds.). 2021. *Smart Cities and Smart Governance: Towards the 22nd Century Sustainable City*. Public Administration and Information Technology. Cham: Springer International Publishing.

Fahrradbüro Münster. 2022. "Interview on the urban cycling dashboard - discussion of preliminary results from the perspective of urban cycling planning."

Fermazin, F. 2021. "A Proposal for an Automated Sustainability Assessment Algorithm for the Cycling Infrastructure in Münster." Bachelor. Münster: Westfälische Wilhelms-Universität.

Fernández-Heredia, Á., A. Monzón, and S. Jara-Díaz. 2014. "Understanding cyclists' perceptions, keys for a successful bicycle promotion." *Transp. Res. Part Policy Pract.*, 63: 1–11. https://doi.org/10.1016/j.tra.2014.02.013.

Ferster, C., J. Fischer, K. Manaugh, T. Nelson, and M. Winters. 2020. "Using OpenStreetMap to inventory bicycle infrastructure: A comparison with open data from cities." *Int. J. Sustain. Transp.*, 14 (1): 64–73. https://doi.org/10.1080/15568318.2018.1519746.

FixMyCity GmbH. 2022. "FixMyBerlin." Accessed January 11, 2022. https://fixmyberlin.de/.

Furth, P. G., M. C. Mekuria, and H. Nixon. 2016. “Network Connectivity for Low-Stress Bicycling.” *Transp. Res. Rec. J. Transp. Res. Board*, 2587 (1): 41–49. https://doi.org/10.3141/2587-06.

Harker, P. T. 1987. “Incomplete pairwise comparisons in the analytic hierarchy process.” *Math. Model.*, 9 (11): 837–848. https://doi.org/10.1016/0270-0255(87)90503-3.

Harris, T., and D. Weiner. 1998. “Empowerment, Marginalization, and ‘Community-integrated’ GIS.” *Cartogr. Geogr. Inf. Syst.*, 25 (2): 67–76. https://doi.org/10.1559/152304098782594580.

Healy, K. 2018. *Data visualization: a practical introduction*. Princeton, NJ: Princeton University Press.

Heinen, E., B. van Wee, and K. Maat. 2010. “Commuting by Bicycle: An Overview of the Literature.” *Transp. Rev.*, 30 (1): 59–96. https://doi.org/10.1080/01441640903187001.

Holtz, Y. 2018. “The Radar chart and its caveats.” Accessed December 16, 2021. https://www.data-to-viz.com/caveat/www.data-to-viz.com/caveat/spider.html.

Hull, A., and C. O’Holleran. 2014. “Bicycle infrastructure: can good design encourage cycling?” *Urban Plan. Transp. Res.*, 2 (1): 369–406. https://doi.org/10.1080/21650020.2014.955210.

IG Fahrradstadt Münster e.V. 2021. “Interview on the urban cycling dashboard - discussion of preliminary results from cyclists' point of view.”

Jing, C., M. Du, S. Li, and S. Liu. 2019. “Geospatial Dashboards for Monitoring Smart City Performance.” *Sustainability*, 11 (20): 5648. https://doi.org/10.3390/su11205648.

Karduni, A., I. Cho, G. Wessel, W. Ribarsky, E. Sauda, and W. Dou. 2017. “Urban Space Explorer: A Visual Analytics System for Urban Planning.” *IEEE Comput. Graph. Appl.*, 37 (5): 50–60. https://doi.org/10.1109/MCG.2017.3621223.

Kazemzadeh, K., A. Laureshyn, L. Winslott Hiselius, and E. Ronchi. 2020. “Expanding the Scope of the Bicycle Level-of-Service Concept: A Review of the Literature.” *Sustainability*, 12 (7): 2944. https://doi.org/10.3390/su12072944.

Kessler, F. 2011. “Volunteered Geographic Information: A Bicycling Enthusiast Perspective.” *Cartogr. Geogr. Inf. Sci.*, 38 (3): 258–268. https://doi.org/10.1559/15230406382258.

Kitchin, R., T. P. Lauriault, and G. McArdle. 2015. “Knowing and governing cities through urban indicators, city benchmarking and real-time dashboards.” *Reg. Stud. Reg. Sci.*, 2 (1): 6–28. https://doi.org/10.1080/21681376.2014.983149.

Kitchin, R., and G. McArdle. 2017. “Urban data and city dashboards: Six key issues.” *Data City*, 111–126. Abingdon, Oxon ; New York, NY: Routledge.

Latham, A., and P. R. H. Wood. 2015. “Inhabiting Infrastructure: Exploring the Interactional Spaces of Urban Cycling.” *Environ. Plan. Econ. Space*, 47 (2): 300–319. https://doi.org/10.1068/a140049p.

Lazar, J. 2017. *Research methods in human computer interaction*. Cambridge, MA: Elsevier.

Leitinger, S., A. Wagner, and W. Kremser. 2020. "Erfahrungen bei der Umsetzung eines Datenmanagementplans für räumliche Daten des Radverkehrs." *AGIT - J. Für Angew. Geoinformatik*, (6): 255–262.

Linneberg, M. S., and S. Korsgaard. 2019. "Coding qualitative data: a synthesis guiding the novice." *Qual. Res. J.*, 19 (3): 259–270. https://doi.org/10.1108/QRJ-12-2018-0012.

Liu, G., S. Krishnamurthy, and P. van Wesemael. 2021. "Conceptualizing cycling experience in urban design research: a systematic literature review." *Appl. Mobilities*, 6 (1): 92–108. https://doi.org/10.1080/23800127.2018.1494347.

Lock, O., T. Bednarz, S. Z. Leao, and C. Pettit. 2020. "A review and reframing of participatory urban dashboards." *City Cult. Soc.*, 20: 100294. https://doi.org/10.1016/j.ccs.2019.100294.

Loidl, M., A. Wagner, and D. Kaziyeva. 2020. "Bicycle Observatory – eine räumlich differenzierte, kontinuierliche Beobachtung der Fahrradmobilität." *AGIT - J. Für Angew. Geoinformatik*, (6): 263–271.

Lowry, M. B., D. Callister, M. Gresham, and B. Moore. 2012. "Assessment of Communitywide Bikeability with Bicycle Level of Service." *Transp. Res. Rec. J. Transp. Res. Board*, 2314 (1): 41–48. https://doi.org/10.3141/2314-06.

Manton, R., H. Rau, F. Fahy, J. Sheahan, and E. Clifford. 2016. "Using mental mapping to unpack perceived cycling risk." *Accid. Anal. Prev.*, 88: 138–149. https://doi.org/10.1016/j.aap.2015.12.017.

Marquart, H., U. Schlink, and M. Ueberham. 2020. "The planned and the perceived city: A comparison of cyclists' and decision-makers' views on cycling quality." *J. Transp. Geogr.*, 82: 102602. https://doi.org/10.1016/j.jtrangeo.2019.102602.

Marzouki, A., F. Lafrance, S. Daniel, and S. Mellouli. 2017. "The relevance of geovisualization in Citizen Participation processes." *Proc. 18th Annu. Int. Conf. Digit. Gov. Res.*, 397–406. Staten Island NY USA: ACM.

McArdle, G., and R. Kitchin. 2016. "The Dublin Dashboard: Design and development of a real-time analytical urbn dashboard." *ISPRS Ann. Photogramm. Remote Sens. Spat. Inf. Sci.*, IV-4/W1: 19–25. https://doi.org/10.5194/isprs-annals-IV-4-W1-19-2016.

Milakis, D., and K. Athanasopoulos. 2014. "What about people in cycle network planning? applying participative multicriteria GIS analysis in the case of the Athens metropolitan cycle network." *J. Transp. Geogr.*, 35: 120–129. https://doi.org/10.1016/j.jtrangeo.2014.01.009.

Nakazawa, M. 2021. *fmsb: Functions for Medical Statistics Book with some Demographic Data*. R.

Nelson, T. 2021. "BikeMaps." Accessed October 11, 2021. https://bikemaps.org/.

Nelson, T., T. Denouden, B. Jestico, K. Laberee, and M. Winters. 2015. "BikeMaps.org: A Global Tool for Collision and Near Miss Mapping." *Front. Public Health*, 3. https://doi.org/10.3389/fpubh.2015.00053.

Nelson, T., C. Ferster, K. Laberee, D. Fuller, and M. Winters. 2021. “Crowdsourced data for bicycling research and practice.” *Transp. Rev.*, 41 (1): 97–114. https://doi.org/10.1080/01441647.2020.1806943.

Nikolaeva, A., M. te Brömmelstroet, R. Raven, and J. Ranson. 2019. “Smart cycling futures: Charting a new terrain and moving towards a research agenda.” *J. Transp. Geogr.*, 79: 102486. https://doi.org/10.1016/j.jtrangeo.2019.102486.

Oliveira, F., D. Nery, D. G. Costa, I. Silva, and L. Lima. 2021. “A Survey of Technologies and Recent Developments for Sustainable Smart Cycling.” *Sustainability*, 13 (6): 3422. https://doi.org/10.3390/su13063422.

Pajarito, D. F. 2018. “Mobile Services for Green Living.” PhD. Castelló de la Plana: Universitat Jaume I.

Pajarito, D. F., A. Degbelo, and M. Gould. 2020. “Collaboration or competition: The impact of incentive types on urban cycling.” *Int. J. Sustain. Transp.*, 14 (10): 761–776. https://doi.org/10.1080/15568318.2019.1627619.

Pajarito, D. F., and M. Gould. 2018. “Mapping Frictions Inhibiting Bicycle Commuting.” *ISPRS Int. J. Geo-Inf.*, 7 (10): 396. https://doi.org/10.3390/ijgi7100396.

Pajarito, D. F., and S. Maas. 2018. “Mapping cyclists’ routes: involving citizens in collecting open cycling data.” 7.

Pánek, J., and K. Benediktsson. 2017. “Emotional mapping and its participatory potential: Opinions about cycling conditions in Reykjavík, Iceland.” *Cities*, 61: 65–73. https://doi.org/10.1016/j.cities.2016.11.005.

Pickles, J. 1995. *Ground truth: The social implications of geographic information systems*. Guilford Press.

Popan, C. 2019. *Bicycle utopias: imagining fast and slow cycling futures*. Routledge advances in sociology. New York: Routledge.

Poplin, A. 2017. “Cartographies of Fuzziness: Mapping Places and Emotions.” *Cartogr. J.*, 54 (4): 291–300. https://doi.org/10.1080/00087041.2017.1420020.

Psarikidou, K., D. Zuev, and C. Popan. 2020. “Sustainable cycling futures: can cycling be the future?” *Appl. Mobilities*, 5 (3): 225–231. https://doi.org/10.1080/23800127.2020.1845073.

Pucher, J., and R. Buehler. 2017. “Cycling towards a more sustainable transport future.” *Transp. Rev.*, 37 (6): 689–694. https://doi.org/10.1080/01441647.2017.1340234.

Rau, H., and J. Scheiner. 2020. “Sustainable Mobility: Interdisciplinary Approaches.” *Sustainability*, 12 (23): 9995. https://doi.org/10.3390/su12239995.

Robinson, A. 2017. “Geovisual Analytics.” *Geogr. Inf. Sci. Technol. Body Knowl.*, 2017 (Q3). https://doi.org/10.22224/gistbok/2017.3.6.

Roth, R. E. 2013. “Interactive maps: What we know and what we need to know.” *J. Spat. Inf. Sci.*, (6): 57.

Rowley, J., and F. Slack. 2004. “Conducting a literature review.” *Manag. Res. News*, 27 (6): 31–39. https://doi.org/10.1108/01409170410784185.

Saaty, T. L. 1990. “How to make a decision: The Analytic Hierarchy Process.” *Eur. J. Oper. Res.*, (48): 9–26.

Saaty, T. L. 2003. “Decision-making with the AHP: Why is the principal eigenvector necessary.” *Eur. J. Oper. Res.*, 7.

Saaty, T. L. 2008. “Decision making with the analytic hierarchy process.” *Int. J. Serv. Sci.*, 1 (1): 83. https://doi.org/10.1504/IJSSCI.2008.017590.

Saaty, T. L., and L. T. Tran. 2007. “On the invalidity of fuzzifying numerical judgments in the Analytic Hierarchy Process.” *Math. Comput. Model.*, 46 (7–8): 962–975. https://doi.org/10.1016/j.mcm.2007.03.022.

Sardain, A., C. Tang, and C. Potvin. 2016. “Towards a dashboard of sustainability indicators for Panama: A participatory approach.” *Ecol. Indic.*, 70: 545–556. https://doi.org/10.1016/j.ecolind.2016.06.038.

Schmid-Querg, J., A. Keler, and G. Grigoropoulos. 2021. “The Munich Bikeability Index: A Practical Approach for Measuring Urban Bikeability.” *Sustainability*, 13 (1): 428. https://doi.org/10.3390/su13010428.

Schröder, A. 2021. “Fahrradstraßen 2.0: Mehr Raum und Aufmerksamkeit für den Radverkehr in Münster.” *Standort*, 45 (2): 77–82. https://doi.org/10.1007/s00548-021-00709-7.

Smart City Münster. 2021a. “Smart City Münster Dashboard.” Accessed September 14, 2021. https://dashboard.smartcity.ms/.

Smart City Münster. 2021b. “Fahrradnetz 2.0 Münster – Einfach. Smart. Münster.” Accessed September 14, 2021. https://smartcity.ms/fahrradnetz-2-0-muenster/.

Smart City Münster. 2022. “Interview on the urban cycling dashboard - discussion of preliminary results from the perspective of a smart city.”

Snizek, B., T. A. Sick Nielsen, and H. Skov-Petersen. 2013. “Mapping bicyclists’ experiences in Copenhagen.” *J. Transp. Geogr.*, 30: 227–233. https://doi.org/10.1016/j.jtrangeo.2013.02.001.

Soliz, A. 2021. “Creating Sustainable Cities through Cycling Infrastructure? Learning from Insurgent Mobilities.” *Sustainability*, 13 (16): 8680. https://doi.org/10.3390/su13168680.

Stadt Münster. 2016. “Stadt Münster: Verkehrsplanung - In Münster unterwegs mit dem Rad - Radverkehrskonzept.” Accessed February 11, 2022. https://www.stadt-muenster.de/verkehrsplanung/mit-dem-rad/radverkehrskonzept.

Stadt Münster. 2018. “Fahrradstadtplan.” Münster.

Stadt Münster. 2020a. *Mobilitätsbefragung zum werktäglichen verkehrsverhalten der Bevölkerung in der Stadt Münster*. 26.

Stadt Münster. 2020b. “Maßnahmen Radverkehr in Münster ab 2020.” Accessed September 14, 2021. https://geo.stadt-muenster.de/radverkehrsmassnahmen/.

Stadt Münster. 2021a. “Stadt Münster: Verkehrsplanung - In Münster unterwegs mit dem Rad - Parkmöglichkeiten.” Accessed September 14, 2021. https://www.stadt-muenster.de/verkehrsplanung/mit-dem-rad/parkmoeglichkeiten.

Stadt Münster. 2021b. "Stadt Münster: Verkehrsplanung - Kanalpromenade." Accessed February 11, 2022. https://www.stadt-muenster.de/verkehrsplanung/mit-dem-rad/kanalpromenade.

Stadt Münster. 2021c. "Stadt Münster: Verkehrsplanung - In Münster unterwegs mit dem Rad - Fahrradnetz." Accessed February 11, 2022. https://www.stadt-muenster.de/verkehrsplanung/mit-dem-rad/fahrradnetz.

UBA. 2021. "Indikator: Umweltfreundlicher Personenverkehr." Text. Umweltbundesamt. Accessed October 4, 2021. https://www.umweltbundesamt.de/daten/umweltindikatoren/indikator-umweltfreundlicher-personenverkehr.

Ueberham, M., U. Schlink, M. Dijst, and U. Weiland. 2019. "Cyclists' Multiple Environmental Urban Exposures - Comparing Subjective and Objective Measurements." 12.

Ul-Abdin, Z., P. De Winne, and H. De Backer. 2019. "Risk-Perception Formation Considering Tangible and Non-Tangible Aspects of Cycling: A Flemish Case Study." *Sustainability*, 11 (22): 6474. https://doi.org/10.3390/su11226474.

Useche, S., L. Montoro, F. Alonso, and O. Oviedo-Trespalacios. 2018. "Infrastructural and Human Factors Affecting Safety Outcomes of Cyclists." *Sustainability*, 10 (2): 299. https://doi.org/10.3390/su10020299.

WBGU. 2016. *Humanity on the move: Unlocking the transformative power of cities*. Berlin: Wissenschaftlicher Beirat d. Bundesregierung Globale Umweltveränderungen.

Wenzel, A. 2018. "Leezenstadt - mehr Rad für Münster." Accessed December 10, 2021. https://leezenstadt.de/.

Werner, C., and M. Loidl. 2021. "Bicycle Mobility Data: Current Use and Future Potential. An International Survey of Domain Professionals." *Data*, 6 (11): 121. https://doi.org/10.3390/data6110121.

Wickham, H. 2021. *tidyverse: Easily Install and Load the "Tidyverse."* R.

Young, G. W., and R. Kitchin. 2020. "Creating design guidelines for building city dashboards from a user's perspectives." *Int. J. Hum.-Comput. Stud.*, 140: 102429. https://doi.org/10.1016/j.ijhcs.2020.102429..

Young, G. W., R. Kitchin, and J. Naji. 2021. "Building City Dashboards for Different Types of Users." *J. Urban Technol.*, 28 (1–2): 289–309. https://doi.org/10.1080/10630732.2020.1759994.

Appendix

Appendix A: Key literature from literature review 1 and their main findings

Authors	Year	Journal	Title	Refs	Aim	Cycling experiences and infrastructures
Sniezek et al.	2013	Journal of Transport Geography	Mapping bicyclists' experiences in Copenhagen	23	Capturing the cyclists' experiences and statistically relating it to external spatial data	**Cycling experience:** Good, bad **Categories of external factors:** Cycling facilities, street types, urban density and centrality, water and green areas, route-related measures
Fernández Heredia et al.	2014	Transport Research Part A	Understanding cyclists' perceptions, keys for a successful bicycle promotion	64	Investigating attitudes, intentions, perceptions of cyclists to identify the most determinant factors for bicycle usage	**Psycho-social factors influencing bicylce use selection:** - Positive: Efficiency, flexibility, economical, ecological, healthy, fun - Negative: Distance, danger, orography, fitness, climate, comfort, vandalism, facilities **Cyclists' mobility costs:** Out-of-pocket costs, travel time, injury risk, safety, theft risk, comfort **Structural factors:** Bicycle network, additional facilities, safe parking areas

Hull & O'Holleran	2014	Urban, Planning and Transport Research	Bicycle infrastructure: Can good design encourage cycling?	60	Investigating components of cycling infrastructural design and their contribution to a better cycling experience	**Parameters of cycleways:** Coherence, directness, attractiveness, traffic safety, comfort, spatial integration, experience (enjoyable, stressful), social economic value
Milakis & Athanaso-poulos	2014	Journal of Transport Geography	What about people in cycle network planning? Applying participative multicriteria GIS-analysis	59	Prioritizing infrastructural investments participatively with cyclists	**Description of high-quality cycling:** Inexpensive, fast, healthy, and enjoyable **Evaluation criteria:** Ride difficulty, junction density, traffic intensity, traffic speed, legibility, natural environment, built environment, accessibility to activities, centrality, accessibility to urban parks, accessibility to metro/railway stations
Pánek & Benedikts-son	2016	Cities	Emotional mapping and its participatory potential: Opinions about cycling conditions	72	Mapping cycling emotions described with qualitative comments utilizing a geospatial web-based tool	**Cycling emotions:** Good, bad

Manton et al.	2016	Accident, Analysis and Prevention	Using mental mapping to unpack perceived cycling risk	82	Unpacking perceptions of cycling risks, and revealing relations to the actual physical environment	**Cycling experience:** Safety **Infrastructural and traffic factors:** Motorized traffic volume, segregation of cycling facility, road width, number of junctions/roundabouts, parked cars, percentage of heavy goods vehicles
Marquart et al.	2020	Journal of Transport Geography	The planned and the perceived city: A comparison of cyclists' and decisionmakers' views on cycling quality	81	Exploring the decisionmakers' and cyclists' perspective of high-quality cycling	**Determinants of cycling quality:** Built environment, natural environment, personal factors, psychological and social factors **Quality of cycling on individual level:** Safety, flexibility, aesthetics and perception of environment, sense of community, less stressful, noise
Barrero & Rodriguez-Valencia	2021	International Journal of Sustainable Transport	Asking the user: A perceptional approach for bicycle infrastructure design	47	Using cycling perceptions to measure the infrastructural quality of service as an important cyclist-oriented evaluation of cycling infrastructure	**Cycling emotions:** Pleasure, road safety, personal safety **Cycling experiences:** Street attractive-ness, noise pollution, traffic pollution, presence of other cyclists, overcrowded cycling infrastructure, conflicts with pedestrians, street trees **Infrastructural cycling. experiences:** Infrastructural service, pavement, road signs, traffic lights, avoidance of vehicle lines

Liu et al.	2021	Applied Mobilities	Conceptualizing cycling experience in urban design research: a systematic literature review	44	Conceptualization and categorization of cycling experiences and their related research methodologies	**Social experience:** Interaction with other people on the street, normality and image of cycling, participation in the traffic system, freedom of movement **Spatial experience:** Mental map, sense of enclosure, landmarks, wayfinding, affordances, spatial identity, and relation to place **Sensory experience:** Feel of bicycle, carrying goods and people, weather, threat of safety, smell vision, sound, skill competencies

Appendix B: Questionnaire with tasks for the user survey

Section	Task	Role	Question	Explanation	Respond options
Section 0	Task 0: Role selection	Both	Sie können diese Umfrage aus einer der zwei folgenden Perspetiven ausfüllen	Radfahrer*in / Bürger/in: Als Radfahrer*in und Bürger*in in Münster sollten Sie regelmäßige Radfahr-Erfahrungen in Münster gemacht haben. Entscheidungsträger*in: Als Entscheidungsträger*in sollten Sie durch ihre berufliche Tätigkeit in Planung oder Entscheidungen bezüglich von Mobilität und Infrastruktur in Münster involviert sein.	• Radfahrer*in / Bürger*in • Entscheidungs-träger*in • Ich fühle mich zu keiner der beiden Gruppen zugehörig (nicht an der Studie teilnehmen)
Section 1	Task 1: Prioritization of cycling infrastructure	Both	Bitte wägen Sie alle Bestandteile der Rad-Infrastruktur gegeneinander ab. Setzen Sie pro Zeile/Gegenüber-stellung Ihre Priorität (1,2,3, oder 4) in Richtung des für Sie wichtigeren Bestandteils von Rad-Infrastruktur. Falls beide Bestand-teile für Sie gleichwertig sind, wählen Sie	Rad-Verkehrsmaßnahmen Maßnahmen zur Eingliederung und Erleichterung von Radfahren im normalen Straßenverkehr (z.B. Fahrradampeln, Radstreifen) Qualität des Parkens Möglichst qualitativ hochwertiges Parken von Rädern (z.B. Wetter- und Diebstahl-geschützt)	21 prioritizations between each unique pair of subfactors, as the following example Qualität des Parkens 4 3 2 1 0 1 2 3 4 • Rad-Priorisierung

die Mitte (0). Falls Sie keine Angabe machen können, wählen Sie k.A. aus.
HINWEIS: Konzentrieren Sie sich auf die jeweils einzelne Priorisierung zweier Bestandteile! Sie müssen keine zeilenübergreifend konsistente Priorisierung abgeben!

Rad-Priorisierung
Klare Priorität von Radfahrer*innen im Straßenverkehr (z.B. Expressstraße der Promenade, oder Fahrradstraßen 2.0)
Weg-Beschilderung
Häufige, leicht zu erkennende und leicht verständliche Wegweiser zur Navigation im Radwegenetz
Reparaturmöglichkeiten
Gute Erreichbarkeit und Verfügbarkeit von jeglichen Reparaturmöglichkeiten (z.B. öffentliche Fahrradpumpe mit Werkzeugen)
Radwege-Netz
Zusammenhängendes, lückenloses Radwegenetz, sowie Anschluss an größere Radwegenetze (z.B. zwischen Stadt-Land)
Parkmöglichkeiten
Gute Erreichbarkeit und Verfügbarkeit von jeglichen Parkmöglichkeiten (z.B. einfache Parkbügel)

Section 1	Task 2: Prioritization of cycling emotions	Both	Bitte wägen Sie alle Radfahr-Emotionen gegeneinander ab. Bitte setzen Sie erneut Ihre Priorität pro Zeile/Gegenüber-stellung, diesmal bezüglich der Radfahr-Emotionen. HINWEIS: Konzentrieren Sie sich auf die jeweils einzelne Priorisierung zweier Emotionen! Sie müssen keine zeilenüber-greifend konsistente Priorisierung abgeben!	Erholung Radfahren als gesundheitsfördernde Alltagsmobilität (z.B. als Erholung in natürlicher Umgebung, frische und saubere Luft) Freude Freude während des Radfahrens (z.B durch schöne Stadtumgebung) Sicherheit Sicherheit während des Radfahrens und beim Parken des Rads Schnelle Fahrt Möglichst geringe Fahrzeit von A nach B Komfort Komfortables und flexibles Radfahren im Straßenverkehr	10 prioritizations between each unique pair of subfactors, as the following example Freude 4 3 2 1 0 1 2 3 4 Sicherheit
Section 1	Task 3: Prioritization between cycling emotions and cycling infrastructure	Both	Abschließend bitten wir Sie abzuwägen, welche Sichtweise der Radverkehrsqualität wichtiger für Sie ist: Die materiellen Bestandteile der Rad-Infrastruktur oder Ihre persönlichen Emotionen.		Radfahr-Emotionen 4 3 2 1 0 1 2 3 4 Rad-Infrastruktur

			Bitte setzen Sie erneut Ihre Priorität.		
Section 2	Task 4: Motivations of usage purposes	CC	Wie hoch ist Ihre Motivation (1-100) das Radfahr-Dashboard zu nutzen, um… Bitte nutzen Sie den Schieberegler für alle drei Möglichkeiten!	Generelle Informationen z.B. Lage von Fahrradstraßen, städtische Qualitätsunterschiede der Radinfrastruktur Persönliche Meinungen und Erfahrungen z.B. gefährliche Kreuzungen oder besonders gelungene Abschnitte der Radinfrastruktur, Abstimmung zu Verkehrsversuchen Aktuelles z.B. Verkehrsversuche, Erneuerungen, Baustellen	1. … sich über **generelle Informationen** der Rad-infrastruktur in Münster zu erkundigen? (1-100) 2. … ihre **persönlichen Meinungen und Erfahr-ungen** zum Radfahren in Münster den Entscheidungsträger-*innen mitzuteilen? (1-100) 3. … von Entschei-dungsträger*innen über **Aktuelles** der Münster-aner Radinfrastruktur benachrichtigt zu werden? (1-100)see next page)

Section 2	Task 4: Motivations of usage purposes	DM	Wie hoch ist Ihre Motivation (1-100) das Radfahr-Dashboard zu nutzen, um... Bitte nutzen Sie den Schieberegler für alle drei Möglichkeiten!	Spezfische Informationen z.B. stadträumliche Qualitätsunterschiede der Radinfrastrutur hinsichtlich der vorigen Faktoren)) Persönliche Meinungen und Erfahrungen z.B. gefährliche Kreuzungen, besonders gut gelungene Radinfrastruktur, Votings zu Verkehrsversuchen Aktuelles z.B. Verkehrsversuche, Erneuerungen, Baustellen))	1. ... sich über **spezifische Information** der Radinfrastruktur in Münster zu informiern? (1-100) 2. ... .. **persönliche Meinungen und Erfahrungen** zum Radfahren in Münster von Radfahrer*innen / Bürger*innen zu bekommen? (1-100) 3. ... Radfahrer*innen / Bürger*innen über **Aktuelles** der Münsteraner Radinfrastruktur zu benachrichtigen? (1-100)
Section 2	Task 5: Open suggestions	BOTH	Haben Sie Anmerkungen/ Vorschläge zu einem Münsteraner Radfahr-Dashboard, die Sie uns mitteilen wollen?		In den leeren Feldern können Sie optional bis zu drei Anmerkungen/ Vorschläge geben.

Section 3	Task closing: Cycling frequency	Both	Wie oft benutzen Sie Ihr Rad?	Single-choice question	• Jeden Tag • Mehrmals in der Woche • Mehrmals im Monat • Selten
Section 3	Task closing: Age	Both	Wie alt sind Sie?	Single-choice question	• Jünger als 20 Jahre • 20-24 Jahre • 25-29 Jahre • 30-34 Jahre • 35-39 Jahre • 40-44 Jahre • 45-49 Jahre • 50-54 Jahre • 55-59 Jahre • 60-64 Jahre • 65 Jahre oder älter
Section 3	Task closing: Attention	Both	Konnten Sie die Umfrage unabgelenkt und nach den jeweiligen Instruktionen ausführen?	Multiple-choice question or one open comment	• Ich habe alle Aufgaben aufmerksam und nach den Instruktionen

					• Manchmal habe ich irgendetwas geklickt, weil ich mich einfach nicht ausgekannt habe. • Ich habe häufig irgendetwas angeklickt, damit ich schnell fertig werde. • Manchmal habe ich irgendetwas geklickt, weil ich unmotiviert oder abgelengkt war • Ich wurde während des Ausfüllens der Umfrage durch meine Umwelt häufig abgelenkt
Section 3	Task closing: Willingness	Both	Haben Sie gerne an dieser Studie teilgenommen?	Sinlge-choice question	• Nein • Eher nein • Eher ja • Ja

C: Validity conditions of the survey tasks

Task	Number of entries	Validity condition
0: Role selection	1	Is answered
1: Prioritization of cycling infrastructure	21	At least 90 % answered
2: Prioritization of cycling emotions	10	At least 90 % answered
3: Prioritization between cycling infrastructures and emotions	1	Is answered
4: Motivations of usage purposes	3	At least two motivations given
5: Open suggestions	1-3	At least one open suggestions
6: Closing questions (age, frequency of bike usage, motivation & severity of participation)	4 tasks	At least three tasks answered

D1: Key literature from literature and dashboard review 2

Authors	Year	Journal/Book	Title	Refs	Main objective	Related dashboard(s)
Kitchin & McArdle.	2017	Book: Data and the city	Chapter: Urban data and city dashboards: Six key issues	49	Highlighting conceptual and practical shortcomings of urban dashboards **Six key issues:** Epistemology, scope and access, veracity and validity, usability and literacy, use and utility, and ethics	Dublin Dashboard
Jing et al.	2019	Journal: Sustainability	Geospatial Dashboards for Monitoring Smart City Performance	102	Review of research on and development of geospatial dashboards including issues of spatial data, analysis, and its visualization, as well as aspects on architecture and design	**Selection of reviewed dashboards:** London City Dashboard Dublin Dashboard Bandung Dashboard Edmonton Citizen's Dashboard Boston Performance Management Skopje Dashboard Sydney City Dashboard Iowa Dashboard Alaska HMIS Dashboard OSU Columbus Dashboard

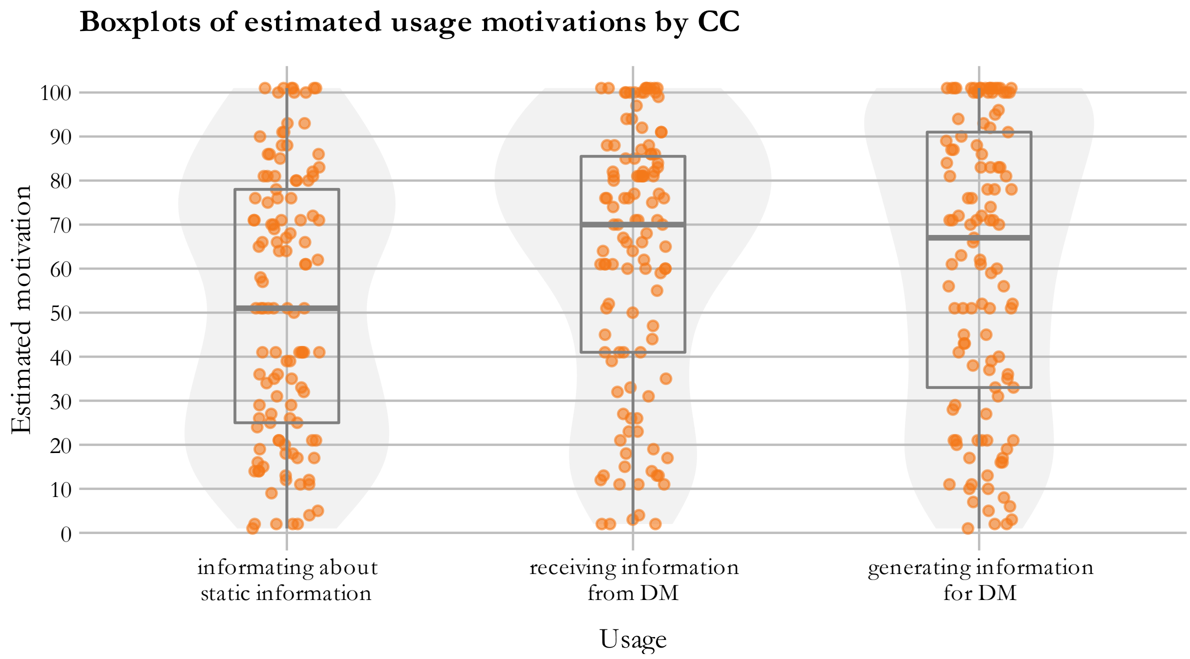
Lock et al.	2020	Journal: City, Culture and Society	A review and reframing of participatory urban dashboards	75	Review of participatory and collaborative urban dashboards and its conceptualization in the frame of other existing digital urban planning methods or tools	**Selection of reviewed dashboards:** London City Dashboard Sydney City Dashboard Edmonton Citizen's Dashboard Boston CityScore Smart Citizen Sentiment - Dashboard London Situation Room BikeMaps Free to Be SafetiPin
Young and Kitchin	2020	Journal: International Journal of Human-Computer Studies	Creating design guidelines for building city dashboards from a user's perspectives	62	User experience study on four urban dashboards to create common guidelines for building city dashboards	London City Dashboard Dublin Dashboard New York Dashboard Hawaii Dashboard
Brocza & Kollarits	2020	Journal: AGIT - Journal für angewandte Geoinformatik	Bicycle Dashboard: Everything in View	7	Conceptualization of a bicycle dashboard focusing on potential cycling-related data, its analysis and visualization	Bicycle Observatory project ZGIS University of Salzburg

Leitinger et al.	2020	Journal: AGIT - Journal für angewandte Geoinformatik	Experiences in the Implement-ation of a Data Management Plan for Spatial Data of Bicycle Traffic	13	Managing a variety of spatio-temporal data on cycling for its open data usage on a bicycle dashboard	Bicycle Observatory project ZGIS University of Salzburg
Loidl et al.	2020	Journal: AGIT - Journal für angewandte Geoinformatik	Bicycle Observatory - Continuously Monitoring Spatial Variations of Cycling Mobility	11	Utilizing the concept of an geographic information observatory to enrich public data availability of urban cycling and support its systematic understanding	Bicycle Observatory project ZGIS University of Salzburg
Young et al.	2021	Journal: Journal of Urban Technology	Building City Dashboards for Different Types of Users	65	Identifying user types of urban dashboards and evaluate their experience of four urban dashboards regarding its user-centric design	London City Dashboard Dublin Dashboard New York Dashboard Hawaii Dashboard

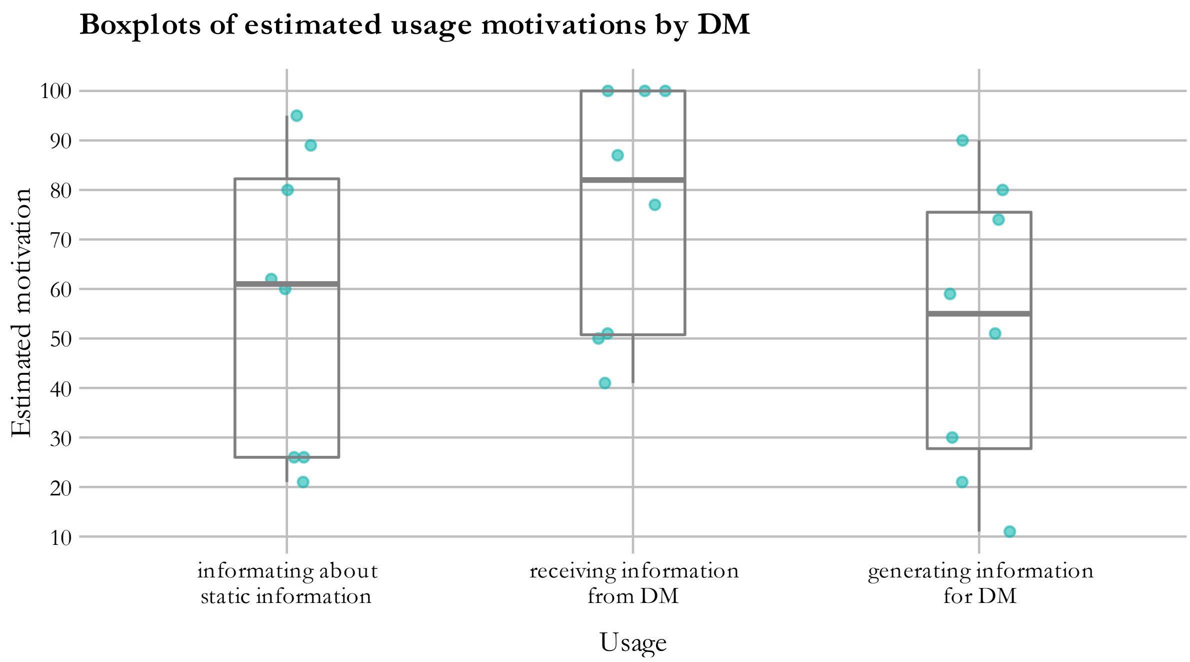
D2: Reviewed urban dashboards and digital platforms in literature and dashboard review 2

Title	Provider	URL	Objectives	First accessed
BikeMaps	University of Victoria	https://bikemaps.org/	Participatory platform for mapping and visualizing worldwide cycling experiences related to safety hazards	2021-10-11
FixMyBerlin	FixMyCity GmbH	https://fixmyberlin.de/	Participatory platform to enable a data-based dialogue on cycling experiences and projects between planners and citizens	2022-01-11
Leezenstadt Münster	Wenzel, Albert Kaktus - Grüne Jugend Münster Bündnis 90/Die Grünen GAL Münster	https://leezenstadt.de/	A participatory deficiency reporter regarding cycling infrastructure in Münster	2021-12-10
Smart City Dashboard Münster	Smart City Münster	https://dashboard.smartcity.ms/	A tile-based or map centered dashboard for Münster monitoring environmental indicators, as well as information on car parking, and passing cyclists or pedestrians	2021-09-14

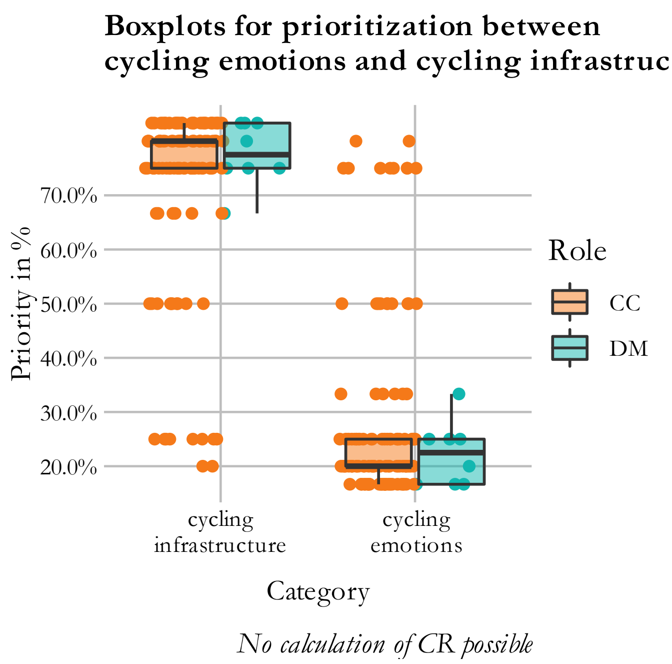
E1: Boxplots for usage motivations by CC



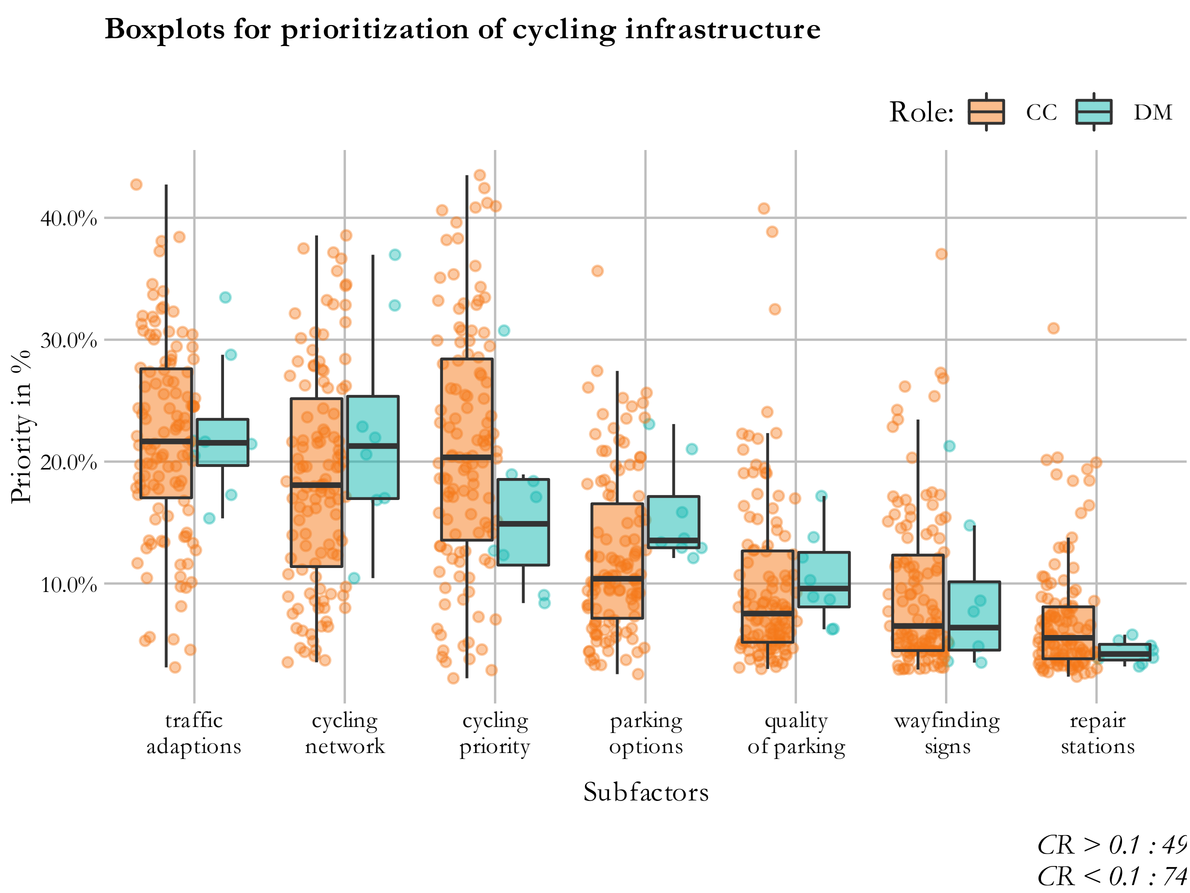
E2: Boxplots for usage motivations by DM



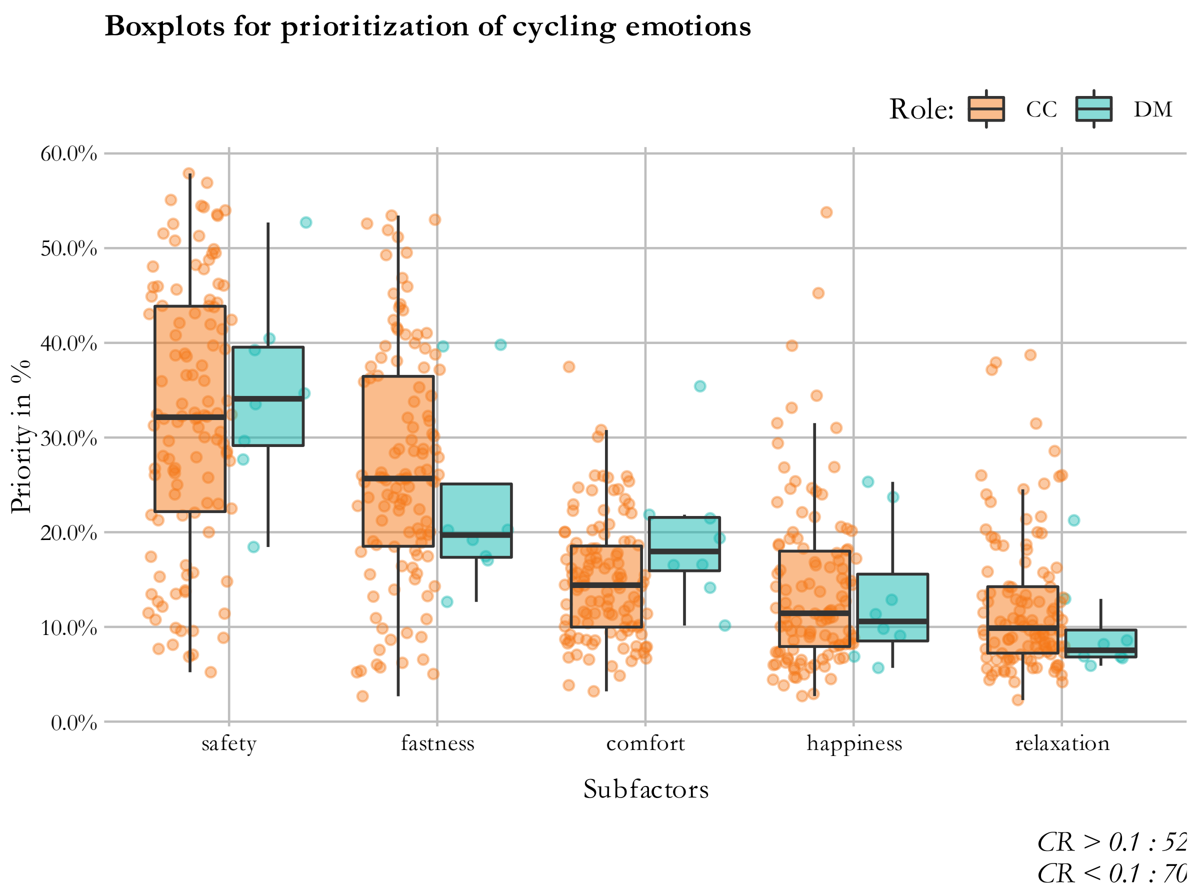
F1: Boxplots for prioritization between cycling infrastructure and cycling emotions



F2: Boxplots for prioritization between subfactors of cycling infrastructure (CR for consisteny ratio)



F3: Boxplots for prioritization between subfactors of cycling emotions (CR for consisteny ratio)



G: Coded open suggestions from the survey

Open suggestion	CODE. PURPOSE	CODE. CONTENT1	CODE. CONTENT2	CODE.SPEC
Alles an einem Ort				One central platform
Der Mehrwert muss so groß sein, dass von Standard-Routen-Angewohnheiten abgewichen wird				Personalization
Erklärungen zu den einzelnen Daten wären gut				Data descriptions
Es darf nicht ein ein Werbetool für Entscheidungsträger*innen ausarten. Über Änderungen informiert werden ist gut. Eine kritische Auseinandersetzung aber auch.				Provider
Es darf nicht ein ein Werbetool für Entscheidungsträger*innen ausarten. Über Änderungen informiert werden ist gut. Eine kritische Auseinandersetzung aber auch.				Exchange-forum
Es muss einen Mehrwert bieten, der sich direkt in der nächsten Fahrt wiederspiegelt				Personalization
Es sollte auch darauf geachtet werden, dass FußgängerInnen nicht zu kurz kommen				Pedestrians
Häufung von einer Meldung von 1 wird erfasst				Report

Ich würde einfach über gängige soziale Plattformen gehen, die eh schon genutzt werden				New platform
Static informationen bitte kompakter und kürzer				Short efficient information
Infrastruktur für Kinder mitbedenken (Spielplätze, Toiletten, ...)				Infrastructure children
Nicht nur aufs reine Stadtgebiet beschränken				Rural
Senf.koeln hat ein ziemlich gut gestaltetes Mittel gefunden, um Kontakt zwischen Bürger*innen und Entscheidungsträger*innen herzustellen. :)				Participation
Unterscheidung Genussradeln Freizeit / berufliche eMobilität Umland / urbaner Alltagsverkehr				Trip purpose
Auslastung Promenade	Static information	Traffic participants	Traffic volume	Real-time
Belegung Radparkhäuser/Fahrradständer	Static information	Infrastructure	Parking	Real-time
Eine Karte mit überdachten Parkmöglichkeiten wäre praktisch.	Static information	Infrastructure	Parking	Map
Es wäre gut, die Parking plätze und ihre Verfügbarkeit zu zählen	Static information	Infrastructure	Parking	Real-time

Fahrrad Routenplanung mit möglichst wenigen Ampeln und guten Straßenbelägen	Static information		Routing with preferences	Preferences
Hinweise über schlechte Wegstrecken! (Ganz wichtig)	Static information	Infrastructure	Quality of cycling lanes	
Static informationen über Parkmöglichkeiten + deren Gestaltung/Ausstattung	Static information	Infrastructure	Parking	Map
Liste von Reparaturwerkstätten, die ZEITNAH einen Termin frei haben	Static information	Infrastructure	Repair	Real-time, appointments
Live Stau karte	Static information	Traffic participants	Traffic volume	Real-time, Map
Parkplatzsuche in der Nähe des Ziels ist möglich	Static information	Infrastructure	Parking	Map
Parkplatzverfügbarkeit Fahrräder am Bahnhof	Static information	Infrastructure	Parking	Real-time
Routenplaner mit PKW Zeitvergleich	Static information		Routing with preferences	Mode preferences
Umsteigemöglichkeiten	Static information		Routing with preferences	Intermodal changes
Welche Radwege sind beleuchtet	Static information	Infrastructure	Quality of cycling lanes	
Wetteraussichten	Static information		Weather	

wo gibt es überdachte Stellplätze	Static information	Infrastructure	Parking	Map
Aktuelle Baustellen	User-generated info	Infrastructure	Construction	
Aktuelle Radfahrer*innen betreffende Baustellen	User-generated info	Infrastructure	Construction	
Bauarbeiten Radinfrastruktur	User-generated info	Infrastructure	Construction	
Baustellen / Umleitungen anzeigen	User-generated info	Infrastructure	Construction 2 Alternative routing	Map
Baustellen /Umleitungen/Müllabholung	User-generated info	Infrastructure	Construction 2 Alternative routing	Waste deposal
Baustellen mitteilen	User-generated info	Infrastructure	Construction	
Baustellen nicht aus irgendwelchen Karten raussuchen	User-generated info	Infrastructure	Construction	Personalization
es könnte aktuelle Infos zu Baustellen und Sperrungen geben	User-generated info	Infrastructure	Construction 2 Closed cycling lanes	

evtl Angaben dazu, welche Wege wegen Baustellen gesperrt sind	User-generated info	Infrastructure	Construction 2 Closed cycling lanes	
Fortschritt und Fertigstellung von Baustellen	User-generated info	Infrastructure	Construction 2 Progress	
Gesperrte Strecken anzeigen	User-generated info	Infrastructure	Closed cycling lanes	
Info über aktuelle abfuckende Umstände, z.B. Baustellen	User-generated info	Infrastructure	Construction	
Konstruktionen und Wege aufzeigen, die sich aus ihnen ergeben	User-generated info	Infrastructure	Construction 2 Alternative routing	
Sperrung Radinfrastruktur	User-generated info	Infrastructure	Closed cycling lanes	
Tagesaktuelle Baustelleninfos/Umleitungen, am liebsten mit Push-Nachricht für Favoriten Stadteile	User-generated info	Infrastructure	Construction 2 Alternative routing	Personalization, Daily
Umleitungen	User-generated info	Infrastructure	Alternative routing	

welche Bereiche haben "Fahrradprojekte"	User-generated info	Infrastructure	Proposals	
Zeitangabe zur Fertigstellung vorhandener Baustellen	User-generated info	Infrastructure	Construction 2 Progress	
Beinahe-Unfälle melden können	User-generated info	Emotion	Safety hazard	Near collisions
Dass man qualitativ schlechte und gefährliche Radwege melden kann	User-generated info	Infrastructure	Quality of cycling lanes	
Einfache Meldung von gefährlichen Verkehrssituationen	User-generated info	Emotion	Safety hazard	
Einfache Meldung von Verbesserungsvorschlägen	User-generated info	Infrastructure	Proposals	
Einfache Möglichkeit Wünsche anzugeben (zb Befarf einer Fahrradgerechten Ampelschaltung)	User-generated info	Infrastructure	Proposals	Fast and easy reporting
EINFACHE Möglichkeit, Probleme zu melden (z.B. Scherben auf Radweg) (das existierende Mängelformular der Stadt MS ist viel zu langwierig)	User-generated info	Infrastructure	Deficiencies	Fast and easy reporting

Es könnte Möglichkeiten geben, Verbesserungsvorschläge und Wünsche zu äußern	User-generated info	Infrastructure	Proposals	
Es wäre gut, wenn man ohne viel Auwand Mängel an der Radinfrastruktur melden könnte.	User-generated info	Infrastructure	Deficiencies	Fast and easy reporting
Falschparker	User-generated info	Traffic participants	Obstructions car	
Feedback zu besonders umbaubedürftigen Stellen geben, regelmäßig (zB halbjährlich) Reaktion auf diese - Transparenz	User-generated info	Infrastructure	Deficiencies 1 Proposals	Feedback, Transparency
Fehlermelder, wenn zum Beispiel ein Schlagloch geschlossen werdne muss	User-generated info	Infrastructure	Deficiencies	
Fotoupload mit Geokoordinaten von KfZ-Behinderungen	User-generated info	Traffic participants	Obstructions car	Photo, Map
Gezielte Hinweise auf Defizite geben	User-generated info	Infrastructure	Deficiencies	
Ich möchte auf einfachem, niedrigschwelligen, schnellen Wege Verbesserungsvorschläge und Ideen einreichen können	User-generated info	Infrastructure	Deficiencies	Fast and easy reporting

Ich möchte mich in einer Art Forum mit anderen Münsteraner Radfahrer*innen über bestimmte Stadtteile/Straßenabschnitte/Wege austauschen können (am besten das Forum ist bereits geographisch (und thematisch) unterteilt, bietet aber auch die Möglichkeit, sich über den Fahrradverkehr in Münster insgesamt auszutauschen. Im besten Falle finden die Ideen der Bürger*innen dann auch noch Berücksichtigung in der Stadtentwicklung und werden umgesetzt.	User-generated info	Infrastructure		Exchange-forum
Ideenvorschläge zu u. a. Gefahrenstellen	User-generated info	Emotion	Proposals	
Interaktive Karte um auf Problempunkte der INfrastruktur hinzuweisen	User-generated info	Infrastructure	Deficiencies	Map
Könnte genutzt werden, um Gefahren- bzw. Unfallstellen für Radfahrer zu kennzeichnen (also Stellen, an denen es häufig zu Unfällen mit Radfahrern kommt)	User-generated info	Emotion	Safety hazard	
Mängelmelder	User-generated info	Infrastructure	Deficiencies	

Mängel-Melder	User-generated info	Infrastructure	Deficiencies	
Mängelmeldungen	User-generated info	Infrastructure	Deficiencies	
Mehr Möglichkeiten zur Interaktion siehe zB www.leezenstadt.de	User-generated info	Infrastructure		Participation
Möglichkeit Gefahrenstellen an Amt zu melden	User-generated info	Emotion	Safety hazard	
Möglichkeit generelle Hinweise auf zu schnell fahrende Autofahrer, Falschparker, mögliche Unfallschwerpunkte u. ä. geben	User-generated info	Traffic participants 1 Emotion	Safety hazard	
Portal für Vorschläge	User-generated info	Infrastructure	Proposals	
Problem/Gefahrenstellen melden	User-generated info	Emotion	Safety hazard	
Straßenkarte mit Markierungsfunktion für Verbesserungspunkte	User-generated info	Infrastructure	Proposals	Map

Wenn mir beim Radfahren eine Schwachstelle im Radverkehrsnetz Münsters auffällt, dann würde ich das gerne direkt den Entscheidungsträger*innen mitteilen	User-generated info	Infrastructure	Deficiencies	Exchange-forum
Infrastruktur-Guide (größere Abstellanlagen, Abkürzungen, ...)	Static information	Infrastructure	Parking	
Erfassung von Infrastrukturelementen (z. B. Parkmöglichkeiten) durch Nutzende des Dahsboards	User-generated info	Infrastructure	Parking	Mapping
Umweltdaten (Regenradar, -wahrscheinlichkeit, Temperatur / gefühlte Temperatur, Dämmerungsanbruch wg. Beleuchtung, ...)	Static information		Weather	
Darstellung wichtiger oder oft missachteter Regeln, ggf. kartenbasierte Darstellung von Fehlverhaltens-Hotspots	Static information	Traffic participants	Cyclists	Map

Declaration of academic integrity

I hereby confirm that this thesis is solely my own work and that I have used no other sources, references, or aids than the ones stated. This thesis has not been submitted in the past or is currently being submitted as an examination work to any other university. It has not been published.

Münster, 23. February 2022