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Unpacking the docked bike-sharing experience. A bike-along study on the infrastructural constraints and determinants of everyday bike-sharing use

Oriol Roig-Costa [a,*], Carme Miralles-Guasch [a,b], Oriol Marquet [a,b]

[a] *Grup d'Estudis en Mobilitat, Transport i Territori (GEMOTT), Geography Department, Universitat Autònoma de Barcelona, Cerdanyola del Vallès, CP 08193 Barcelona, Spain*

[b] *Institute of Environmental Science and Technology, Universitat Autònoma de Barcelona, Cerdanyola del Vallès, CP 08193 Barcelona, Spain*

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ABSTRACT

Cycling for transportation is increasingly recognised as a core strategy to combat the climate emergency, particularly in urban environments. In this frame, bike-sharing systems offer a valuable opportunity to attract new users to cycling and promote sustainable mobility. However, the rapid growth in the use of these schemes has exposed critical gaps, such as insufficient cycling infrastructure, system saturation, or poor integration with other transport modes, which continue to hinder their full potential. By using a mobile methodology, we interviewed 17 docked bike-sharing users in Barcelona to explore how infrastructure and spatial dimensions shape riders' experiences. Our findings reveal that traffic safety - modulated by cycling infrastructure and network connectivity- strongly influences how users of shared bicycles perceive urban spaces. Furthermore, participants reported that features specific to shared bicycles, such as their design and maintenance, notably shaped their riding experiences. Beyond the act of cycling itself, our analysis highlights the importance of often-overlooked stages, such as the bike pick-up and return processes, in shaping users' overall experiences. These moments present logistical and accessibility challenges that could limit the consolidation and expansion of bike-sharing schemes. Policymakers and urban designers are likely to find these insights valuable, as they point to specific improvements that can enhance navigation and positively impact usability and overall user satisfaction.

1. Introduction

Over the past few years, bike-sharing services have evolved from novel experiments to integral components of urban transportation networks, offering a flexible, sustainable alternative to traditional modes of transport (Eren and Uz, 2020; Shaheen et al., 2020; Teixeira et al., 2021). These systems, which differ from traditional bicycles in their shared use, have reshaped the urban landscape by providing a convenient, low-cost transportation option. Additionally, their unique dynamics of access, community use, strategic locations, coverage areas, and technological integration present distinct experiences and challenges that clearly differentiate them from private bicycle use, while maintaining the physical form of bicycles (S. Ji et al., 2024).

Broadly, bike-sharing systems can be categorized into two main types: docked and dockless services. Docked bike-sharing services operate through fixed stations where bicycles are parked. These systems are typically publicly owned and administered, often promoted by local governments. After paying an annual subscription fee, users can enjoy the first few minutes of each trip at no additional cost. They require substantial public investment relative to their scale, commonly financed through taxes, revenue from other municipal services (such as parking fees), or advertising on the vehicles. In return, these systems contribute to the promotion of sustainable and healthy modes of transportation while ensuring affordability for users (Ricci, 2015). By contrast, dockless bike-sharing services are predominantly driven by the private sector and financed through private capital, including venture capital funds and private investors. The most common pricing model for dockless services is pay-per-use, with users required to register via the operator's digital platform. The principal feature of these systems is that they allow vehicles to be parked freely without the need for designated stations. Therefore, the location of the shared bicycles depends on where previous users drop them off, often requiring users to walk to find a bike. However, the dockless model avoids walking at the destination, as riders can end their trip anywhere without needing a docking station (Z. Chen et al., 2020).

It is widely recognised that their establishment in urban

* Corresponding author.
E-mail addresses: oriol.roig@uab.cat (O. Roig-Costa), carme.miralles@uab.cat (C. Miralles-Guasch), oriol.marquet@uab.cat (O. Marquet).

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environments has influenced transportation habits, expanding the appeal of cycling and making it accessible to a broader demographic -especially after the introduction of electric-assisted bikes (Bieliński et al., 2021; Julio and Monzon, 2022). However, each scheme is unique and distinguishable at different levels, and therefore influences transportation habits in different ways. In terms of sociodemographic profile, for instance, differences are observed in their target audience. While docked systems primarily target middle- to high-income city residents, dockless schemes are known to target the wealthier and floating population (Arias-Molinares et al., 2021). Regarding their environmental impact, evidence indicates that both schemes mainly substitute for walking or public transit (Abduljabbar et al., 2021; Z. Chen et al., 2022; Felipe-Falgas et al., 2022; Roig-Costa et al., 2024), although extended life cycle analyses show differences in manufacturing and rebalancing stages (Luo et al., 2019). On a trip level, previous scholars have investigated the spatial and temporal dimensions of both services (McKenzie, 2018), suggesting clear differences in how these two services are used. Specifically, docked bike-sharing systems are generally associated with shorter trip distances and durations (Kou and Cai, 2019; J. Zhang et al., 2016), often serving as first- and last-mile solutions that complement public transportation (Feng et al., 2020; Song et al., 2024). These differences can distinctly influence users' travel plans, most likely disrupting or enhancing riders' trip satisfaction at different ways (Z. Chen et al., 2020). Yet, their interaction with physical space and the broader urban environment is often generalized under the "bike-sharing umbrella". As a result, certain specific aspects of the docked bike-sharing user experience, such as the influence of the fixed station infrastructure on perceptions of reliability, predictability, or parking inflexibility, remain underexplored. More research on these personal factors is needed to better understand how the design of the built environment affects docked bike-sharing behaviour and users' connection to the city.

This study aims to address this gap by focusing on the experiences of docked bike-sharing service users to understand and capture the various subjectivities involved at different stages of their trips. Using mobile methods, which are well-suited for capturing users' in-situ experiences, we seek to understand how environmental settings can shape the entire docked bike-sharing journey—from picking up the bike to parking it at the destination. The paper is organized as follows: Section 2, Background, discusses existing research on bike-sharing and the need for qualitative analysis. Section 3, Methodology, details the innovative approach taken to gather and analyse data. Section 4, Results, presents the findings related to the trip experience of bike-sharing users. Finally, Section 5, Discussion, reflects on the study's implications, concluding with insights for enhancing bike-sharing user experiences and suggestions for policymakers and future research.

2. Background

Previous research on urban cycling has extensively examined the role of the environment in shaping cycling behaviour. Studies have consistently demonstrated a positive correlation between urban cycling and factors such as residential density (Nello-Deakin and Harms, 2019; Yang et al., 2019), street connectivity (Sun et al., 2017), and land use mix diversity (Cervero et al., 2009; Zhao et al., 2020). Proximity to metro stations (Faghih-Imani et al., 2014) and ease of access to city centres (Saghapour et al., 2017) are factors also recognised as significant contributors to increased bicycle usage. In addition to these physical factors, researchers have also explored the significant impact of the social environment on cyclists, such as the interaction with other space users. For instance, in areas with a high volume of motorised vehicles, cyclists often report heightened perceptions of traffic danger (Sun et al., 2017), which leads to reductions in both cycling frequency and volume (Pucher and Buehler, 2016). Careless and reckless driving behaviour further diminishes cyclists' sense of safety significantly (Fruhen and Flin, 2015; Lawson et al., 2013). However, these concerns are not limited to motorised traffic. Cyclists also report feeling unsafe when navigating close to pedestrians, as highlighted by Sanders (2015) and more recent studies (Gkekas et al., 2020; Rossetti et al., 2019), illustrating the complex dynamics between cyclists and other urban actors.

When asked to reflect on these dynamics, urban cyclists tend to show a preference for routes that offer less busy, quieter experience, highlighting safety and comfort as key influences on route choices (Winters and Teschke, 2010). This preference is evident in cyclists' inclination towards routes with continuous cycling facilities and minimal interference, as noted by Lawson et al. (2013). Separated bike lanes, as opposed to shared roads with motorised vehicles, along with wide and well-protected paths, have been consistently found to improve the cycling experience, especially in areas with heavy and fast-moving traffic (Buehler and Dill, 2016; Fraser and Lock, 2011; Handy et al., 2014). Conversely, intersections negatively impact both perceived and objective safety, often discouraging cyclists from choosing those routes (Cicchino et al., 2020; Von Stülpnagel et al., 2022). In an effort to enhance their cycling experience, cyclists may avoid urban elements that slow their pace, such as crosswalks, traffic lights, or stops (McArthur and Hong, 2019; Prato et al., 2018), sometimes even being willing to pedal further to integrate parks and green areas into their trips (Bernardi et al., 2018; Hardinghaus and Nieland, 2021; Lin et al., 2020). Particular elements such as pavement characteristics and street lighting are also believed to impact cycling experiences, although more research is needed in these areas (Buehler and Dill, 2016).

Despite these general trends, environmental factors that influence cycling experiences have been found to vary significantly between different user segments. Sociodemographic characteristics, such as age (Aldred et al., 2017; den Hoed and Jarvis, 2021; Van Cauwenberg et al., 2018) and gender (Cubells et al., 2023b; Hardinghaus and Weschke, 2022), play key roles in shaping how cyclists perceive and respond to physical challenges. Frequency of cycling is another important factor, with more frequent cyclists typically reporting higher perceived safety (Heesch et al., 2014; Lawson et al., 2013; Marín Puchades et al., 2018). Łukawska et al. (2023), for instance, revealed that infrequent cyclists feel less safe on large roads, but this effect could be mitigated by the presence of protected bicycle tracks. This aspect becomes particularly relevant for bike-sharing users, who might lack regular exposure compared to private bicycle owners. As suggested by Caulfield et al. (2012), this can influence their perceived skills and heighten their sensitivity to environmental challenges, most likely influencing route preference. While all types of cyclists tend to share preferences for specific environmental features, such as an inclination for dedicated spaces (Hull and O'Holleran, 2014; Mayers and Glover, 2021) or similar aversion to spots with a high number of intersections (E. Chen and Ye, 2021; Cubells et al., 2023a; Guo and He, 2020), exposure to some other elements affects regular cyclists and bike-sharing users differently. Studies in China (E. Chen and Ye, 2021; Gao et al., 2021) and in the US (Hu et al., 2021), revealed that higher road density positively influences bike-sharing, as it allows easier access to bikes within a short walking range. However, this contrasts with findings on regular urban cyclists, who may feel less comfortable in high-density road network (Fraser and Lock, 2011; Heinen et al., 2010).

In addition, bike-sharing users may be particularly sensitive to certain aspects of cycling infrastructure due to the physical features of shared bicycles. Prior research has demonstrated that hills and steep grades discourage cycling, with cyclists being more sensitive to elevation than pedestrians, and experienced riders showing greater tolerance for such conditions (Cervero and Duncan, 2003). This sensitivity may be amplified in the case of shared bikes, not only given their heavier design, but also due to the less frequent use by the average bike-sharing user. In Alabama, for instance, the physical heaviness of shared bikes was cited as a regular challenge, discouraging many riders from using the service. Similarly, in a study set in Baltimore, women identified concerns about hygiene and bike design as barriers to public bike-sharing (Chavis et al., 2018). Related research has also highlighted how mandatory helmet laws can reduce bike-sharing demand (Fishman et al., 2014; Martin et al., 2012), as bike-sharing users, due to the more spontaneous and shorter characteristics of their trips, are generally less willing to wear helmets compared to private cyclists (Basch et al., 2014; Kraemer et al., 2012). Finally, bike-sharing is particularly sensitive to specific conditions, such as weather. High temperatures, for instance, tend to discourage bike-sharing, although e-bike sharing systems appear to be more resilient to heat conditions (Campbell et al., 2016). Precipitation is another major deterrent for both conventional and electric-assisted shared bicycles (Bean et al., 2024), with Reiss and Bogenberger (2016) finding that rainfall reduces travel demand of shared bike services well below average, not only during rainfall itself, but also for several hours afterward.

The experience of bike-sharing, however, extends far beyond the act of riding itself. A key distinction between regular cycling and bike-sharing -and between docked and dockless schemes- lies in how users engage with the infrastructure and urban space, with stations emerging as a key distinctive element in shaping trip dynamics. In this sense, the location and distribution of bike stations are crucial to the success of any bike-sharing programme (J.-R. Lin and Yang, 2011), with optimal station spacing typically ranging between 250 and 300 m, a distance believed to maximize accessibility for users while minimizing operational and maintenance costs (García-Palomares et al., 2012). High-density areas and city centres are often prioritised, with stations placed near transit hubs and in proximity to residential and commercial areas (Gehrke and Welch, 2019). Studies have shown that bike-sharing stations near residential areas see higher turnover during mornings and weekdays than during evenings and weekends (Mateo-Babiano et al., 2016), which is related to the higher volume of commuting trips. However, as noted by Zhu et al. (2022), return trips often do not follow the same pattern, as some commuters prefer to not return home directly from their workplaces or opt for other travel modes that require less physical effort for their return journey. Additionally, stations should also integrate well with public transport networks and bicycle infrastructure. In Washington DC, for instance, Buck and Buehler (2012) concluded that locating stations near bicycle lanes significantly increased ridership. However, using real-time ridership data, Faghih-Imani et al. (2014) specifically revealed that stations close to major roads experienced lower trip activity compared to those situated along minor roads and bicycle lanes. More recently, some authors have started estimating potential demand through walkability and bikeability indices associated with a given station (Eren and Uz, 2020; Vishkaei et al., 2021).

The micro-design of bike-sharing stations, such as the number of docks, also plays a crucial role in determining their success. A prevalent conclusion is that more docks generally lead to increased usage, particularly during peak times (Y. Ji et al., 2020; Wang and Akar, 2019). This is important because improving bike availability and reducing waiting times can enhance user experience, fostering loyalty and potentially driving more frequent usage and higher overall ridership volumes (Kuo et al., 2021). Station design involves not only understanding the capacity of bike-sharing stations but also how bicycles are distributed throughout the day to accommodate asymmetric travel demand, categorizing stations depending on their role in generating (residential areas) or attracting bike trips (areas of economic activity). Additionally, in order to reach efficient bicycle redistribution some scholars argue that it is equally important to explore station-specific elements such as the clarity of information provided, ease of use, and environmental conditions surrounding the stations (e.g., cleanliness, shade, lighting) (Nogal and Jiménez, 2020). While these factors may seem minor, they can significantly impact user preferences when multiple nearby stations are competing for ridership, particularly in cities where bike-sharing must compete with other transport options like public transit, walking, or private vehicles. In such contexts, subtle differences in station quality can shape the overall success of bike-sharing systems, influencing how attractive they are compared to other modes of transportation.

In summary, quite a few studies have focused specifically on the relationship between physical external factors and bike-sharing usage. However, most of these studies have used a variety of quantitative methods, such as surveys (Campbell et al., 2016), geographic information systems (Kabak et al., 2018) or tracking-based methodologies (Cubells et al., 2023a). Applying qualitative approaches could offer more detailed information about physical environmental factors influencing bike-sharing decisions and could uncover critical features that have not been considered previously. To our knowledge, only a limited number of studies have adopted such qualitative methodologies to examine the built environment's impact on bike-sharing, and these have predominantly relied on sit-down indoor interviews (Jahanshahi et al., 2018; Lyu et al., 2021; Teixeira et al., 2022). Although it is a powerful methodology, conducting interviews indoors generally triggers self-centred and autobiographic responses, compared with more place-oriented narratives produced by mobile methodologies (Evans and Jones, 2011). Additionally, they demand from participants an effort to recollect their experiences and perceptions from the time they were exposed to the physical environment, a task that might prove challenging during the interviews and which can easily translate into recall bias. In contrast, mobile methodologies allow data to be captured in the moment, ensuring it is fresh and reducing the risk of recall bias (Carpiano, 2009). All in all, the literature lacks nuanced insights into how the physical environment influences the overall experience of bike-sharing at a micro level and, consequently, there is a gap in information available for policymakers and urban planners on how to optimally design or redesign urban spaces to encourage bike-sharing among various population groups. Given this limited evidence, we use mobile qualitative research to understand not only which environmental factors are relevant, but also how, why, and where they impact the docked bike-sharing experience. This methodology has previously proven helpful in exploring environmental influences on older adults' transportation cycling experiences (den Hoed and Jarvis, 2021; Van Cauwenberg et al., 2018), in uncovering critical environmental factors for transportation cycling in children (Ghekiere et al., 2014) or in assessing e-bike users' experiences with wayfinding (van Lierop et al., 2020).

3. Method

3.1. Study setting

This study was conducted in the municipality of Barcelona, located on the northwest coast of the Mediterranean Sea, with a population of 1,655,956 (IDESCAT, 2023). Barcelona features over 200 km of cycling infrastructure, including bicycle lanes, bicycle sharrows, and pedestrianised streets. At a modal split level, bicycles account for up to 2.5 % of all trips in the city (EMEF, 2023). Among these trips, the use of *Bicing*, Barcelona's public dock-based bicycle-sharing system, has grown steadily over the years. The system currently operates 519 docked stations -distributed across the city on sidewalks, at chamfer corners, in plazas, at street level by replacing car parking spaces, integrated into bike lanes, or located in bike sharrows (Fig. 1)- and a fleet of 7108 bicycles, of which 4000 are electric (Soriguera and Jiménez-Meroño, 2020). With more than 147,700 members and approximately 50,000 daily trips, *Bicing* bikes now account for one in four bicycles observed on Barcelona's bike lanes (BACC, 2023). Membership costs €50 per year and includes unlimited free usages for trips under 30 min. Trips exceeding 30 min incur an additional fee of €0.70 for each extra 30 min. For electric bikes, an extra €0.35 is charged per trip, and each additional 30 min costs €0.90. Trips exceeding two hours are charged €5 per hour, regardless of whether the bike is mechanical or electric (Bustamante et al., 2022). The *Bicing* bicycles weigh 23 kg for conventional models and 29 kg for electric models, reflecting the robust design tailored to urban usage.

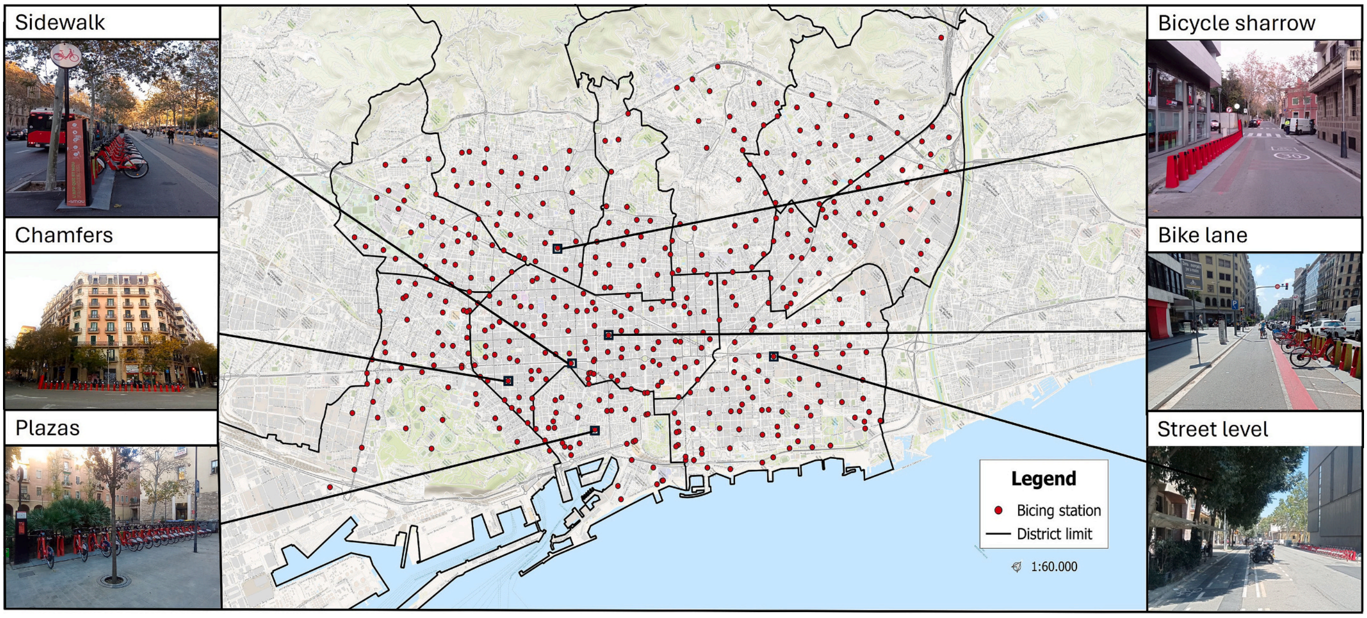

Fig. 1. Public docked-shared bicycle (*Bicing)* stations and station typologies in Barcelona (source: own elaboration).

3.2. Participants recruitment and protocol

During June and July 2022, the first author conducted individual interviews with 17 docked *Bicing* users in Barcelona, all of whom had previously participated in earlier stages of the NEWMOB project (Roig-Costa et al., 2021) and had agreed to be contacted in future phases of the investigation. These participants were re-engaged via WhatsApp and invited to an interview, with no incentives provided for their participation. According to Hennink et al. (2017), code saturation, which represents the point when researchers have gathered enough data, is generally reached after nine participants. After discussing the 17 interviews, the authors reached a consensus that a sufficient number of participants had been achieved.

The data collection involved a double-method approach. First, a mobile interview was conducted during the frame of a natural trip. As the bike-sharing experience goes beyond the single stage of cycling, to obtain in-depth and context-sensitive information, both walk-along interviews (from the origin of the trip to the docked station where the participant picked up the bicycle, and from the docked station where the participant dropped off the bicycle to the trip destination) and bike-along interviews (from the docked station at origin to the docked station at destination) were performed. Subsequently, a static interview took place once the participant's destination was reached. This study was conducted in accordance with ethical research standards. Participants provided informed consent prior to participation, ensuring they were aware of the study's purpose, their voluntary involvement, and their right to withdraw at any time. The study protocol was approved by the ethical committee of the Universitat Autònoma de Barcelona.

3.3. Interviews

Mobile interviews were chosen to capture the full experience and embodied aspects of using a shared bicycle, enabling both the participants and the researcher to move through space together. This approach offers opportunities for discussions about bike-sharing routes, spaces, experiences, and perspectives that might not arise otherwise (Wegerif, 2019). The use of go-along methods, such as bike-along interviews, has been theorised as a way to enhance the understanding of sensory, emotional, and affective dimensions of movement (Spinney, 2015). These methods can elicit detailed verbal accounts that enrich recollection and empathy while providing critical insights into the embodied nature of mobility practices. In that sense, bike-along interviews have been used in prior research to explore the environmental influences on older adults' cycling for transport (Van Cauwenberg et al., 2018) or to examine the environmental influences on primary school children's cycling for transport (Ghekiere et al., 2014), for instance. In our case, mobile interviews were digitally audio recorded, GPS-tracked, and video-documented using a GoProMax camera installed on the researcher's bicycle handlebar. Participants were instructed to select a routine trip from their daily mobility which they would commonly undertake on a regular basis. Drawing from the methodology outlined by Eccles and Arsal (2017), participants were encouraged to share their thoughts and emotions from the beginning to the end of the trip. Recognizing the challenges of maintaining a coherent conversation while cycling, participants were advised against engaging in dialogue with the researcher. Instead, before starting the go-along interviews, the main researcher read out a text with basic instructions encouraging the participants to share their reflections in a think-aloud monologue format, without expecting a response from the researcher. This approach not only prioritised participant safety but also preserved the organic nature and characteristics of the trip, including factors like speed and behaviour. To ensure clear audio capture despite environmental noise, each participant wore a lapel microphone connected to the digital recorder. In those few cases where minor segments were affected by noise interference, we cross-referenced the recordings with GPS-tracked routes and video footage to reconstruct participants' interventions. Additionally, the narrative was enriched using targeted questions, strategically posed at natural pauses such as red traffic lights or intersections. Importantly, the selected route mirrored each participant's habitual route when travelling to that specific destination, ensuring the contextual relevance of the gathered insights. As an example, Fig. 2. displays P01 tracked trip. Additional specific trips for all participants in our study can be found in the Supplementary Materials.

Immediately after the mobile interview, the researcher stopped the video camera and asked the participant for an additional semi-structured interview based on the previous trip. These semi-structured interviews took an average of 25 min and included attitudes, decisions and behaviours engaged by the participant during the recorded trip, together with information regarding participant's weekly bicycle-sharing habits, and whether they owned a private bicycle. This information helped contextualise the trip (Table 1). During this phase of the study, the research team accumulated a total of almost eight hours of

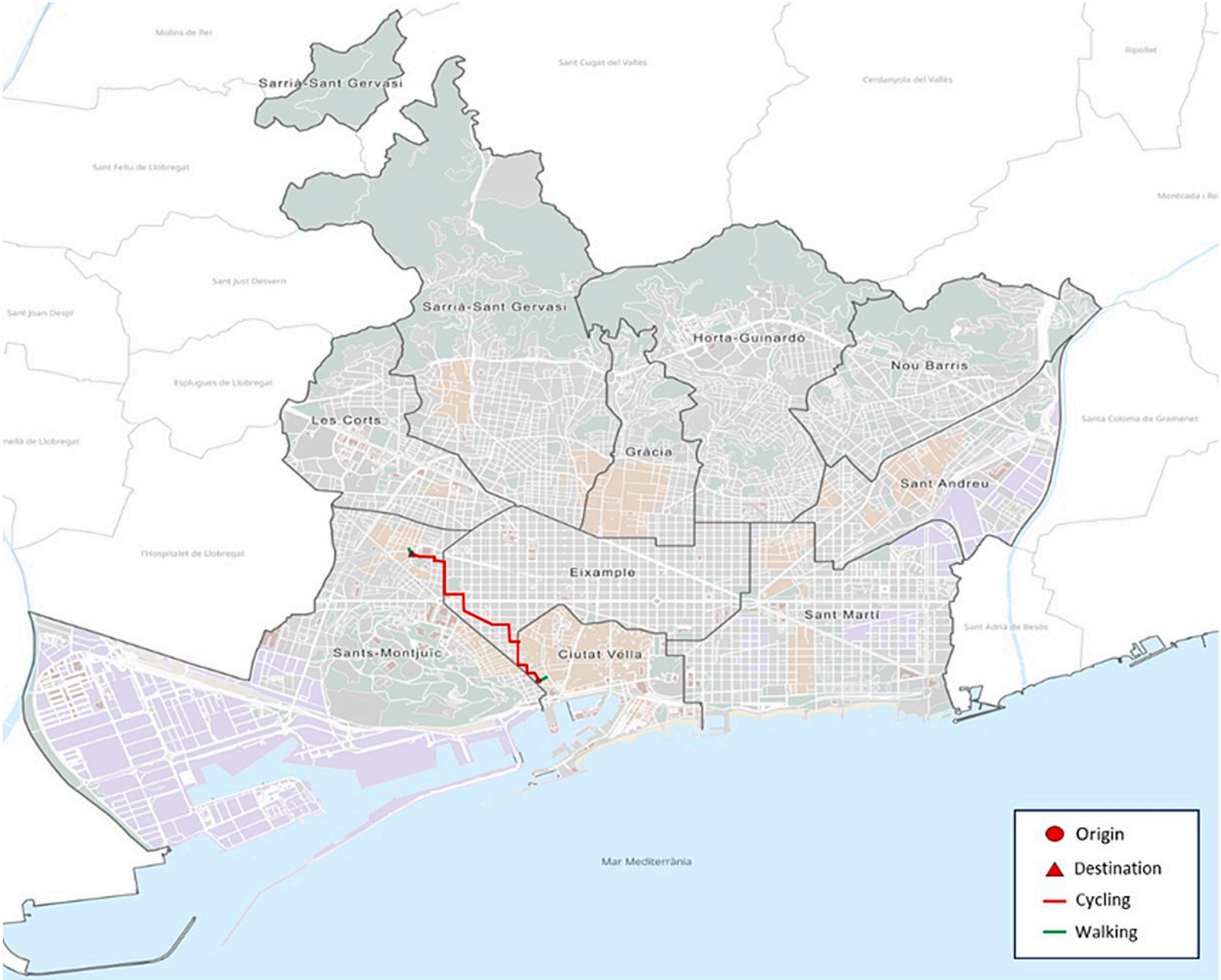

Fig. 2. P01 trip (source: own elaboration).

Table 1
Participants' characteristics and BSS travel related behaviour.

Code	Gender	Age	Bicycle-sharing typology[a]	BSS frequency of use[b]	Bicycle ownership
P01	Man	30	Electric	High	No
P02	Man	31	Electric	Medium	No
P03	Man	39	Conventional	High	No
P04	Man	27	Conventional	Medium	Yes
P05	Woman	42	Conventional	Medium	No
P06	Man	60	Electric	High	No
P07	Man	37	Conventional	Medium	Yes
P08	Woman	45	Conventional	High	Yes
P09	Woman	40	Conventional	High	No
P10	Woman	53	Conventional	Medium	No
P11	Woman	31	Conventional	Medium	No
P12	Woman	24	Conventional	High	No
P13	Man	31	Conventional	Low	No
P14	Man	23	Conventional	Medium	Yes
P15	Man	26	Electric	Medium	No
P16	Man	27	Conventional	Medium	Yes
P17	Woman	28	Electric	Medium	No

[a] During the specific trip in the frame of the mobile interview.
[b] Low: 1 time/week; Medium: 2 or 3 times/week; High: 4 or more times/week.

video and more than 14 h of interviews.

3.4. Analyses

The analysis consisted of two stages. The first stage involved the observation of the videotaped trips. Video recordings of the bike-along interviews were downloaded to the researcher's laptop on the same day the interviews took place, and all audio recordings were transcribed within a week of each interview. The main researcher audited and categorized users' behaviours with the aim of identifying common and discordant patterns in terms of navigating the city. The video data was reviewed alongside the transcripts to capture contextual and non-verbal cues, ensuring a comprehensive understanding of participants' experiences. The second stage involved a thematic analysis of the participants' discourses, combining insights from the trips themselves with those generated during subsequent static interviews. The analysis was conducted collaboratively by the three co-authors: Initial coding was performed independently by two researchers to ensure diverse perspectives, followed by joint discussions. The thematic analysis was conducted systematically, with codes and themes generated inductively from the data and guided by the research objectives. The 'open coding' process, supported by Atlas.ti software, facilitated the organisation, tagging and systematic management of large volumes of qualitative data. Qualitative data was then integrated with quantitative counts of participants who discussed specific environmental factors to support the description of our findings, following the approach outlined by Sandelowski (2001) and Van Cauwenberg et al. (2018). Prevalence of these factors was represented using the following terminology: "few" for factors mentioned by less than 25 % of participants, "some" for 25–50 %, "a lot of" for 50–75 %, and "almost all" for over 75 %. Participant quotes and photographs derived from the recorded videos were included to further illustrate the findings. To ensure the validity of the data, triangulation was applied by cross-referencing findings from video, audio, and field notes to identify consistent patterns. Peer review was conducted through group meetings with colleagues not directly involved in the analysis, where emerging themes and interpretations were discussed and critically evaluated.

4. Results

The inductive qualitative analysis led to a model that identifies the key environmental factors and themes that most influence the overall bike-sharing experience. Based on our material, it becomes evident that the uniqueness of docked bike-sharing systems, compared to regular cycling and dockless bike-sharing, lies in the different stages each bike-sharing user invariably goes through: (1) approaching the dock and picking up the bike; (2) riding to the destination; and (3) arriving at the destination and parking the bike. To respect this uniqueness, the analysis distinguishes each of the three key stages and organises the discourse around this chronological logic (Fig. 3). While *Safety* specifically emerges as the primary and most important issue during the riding stage, *Uncertainty* is identified as the critical issue in both the first and last stages.

4.1. Approaching the docking station and picking up a bike

Issues about *bike availability* emerged as the predominant concern for bike-sharing users during the first stage of the trip. It was judged to be the most important concern during this stage since it was mentioned by almost all participants on their way to the station of origin. The content analysis revealed that bike availability, which was intrinsically surrounded by uncertainty, was at the same time related with the *station infrastructure* characteristics.

4.1.1. Bike availability

At the beginning of the trip, almost all participants shared a feeling of uncertainty when approaching the bike-sharing station. This uncertainty was most of the time related to the supply of bikes and was higher during specific time of the day. Almost all participants described the struggle of finding a bike during peak hours as stressful, mentioning in most of the cases reasons related to time management. A 31-year-old user explained, *"Rush hour is chaotic; finding an available bike feels like winning the lottery."* (P02). Indeed, out of the 17 participants in our study, almost half of them (eight) could not successfully pick up a bike in their first attempt and needed to walk further to the next station to start their ride. Interestingly, although it was common across most of the participants, this feeling of uncertainty surrounding bike availability was more prevalent among participants who started their trip close to high-volume mobility hubs, where the demand for shared bikes is larger. On average, participants starting their trip near big mobility hubs (four), needed to visit double the number of stations and spent more than twice the time before being able to begin their ride compared to those starting at regular stations. In fact, none of them was able to start the trip from their first-option station, having to check between three and seven stations before being able to find an available bike. It was clear how this struggle contributed to fuelling their frustration.

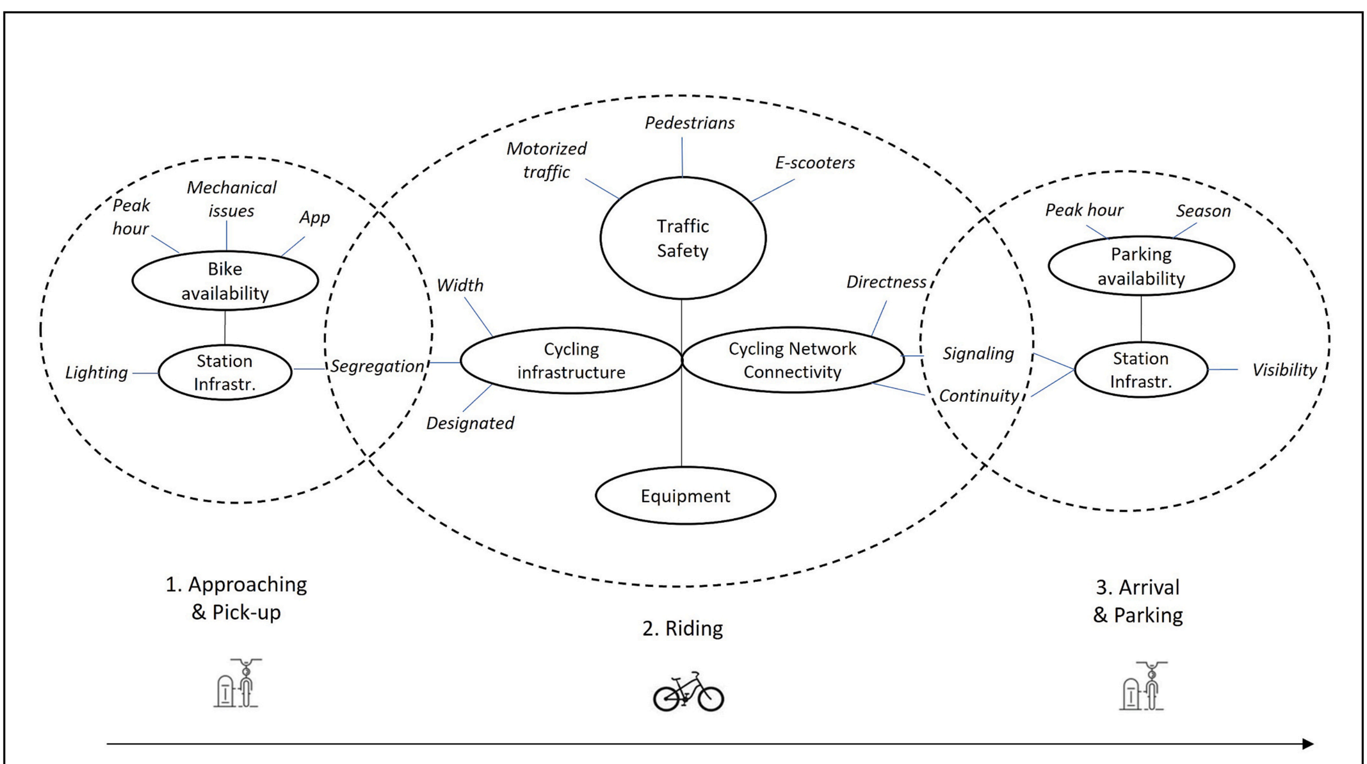

Fig. 3. External aspects influencing the experience of bike-sharing. Model derived from the inductive analysis.

Image 1. Example of a participant encountering bicycle unavailability at a station located near a major mobility hub (source: author's own).

Mechanical issues with the bicycles further amplified this sense of frustration. Some participants declared that problems such as flat tires or non-functioning brakes often turned an already stressful situation into a greater challenge. The uncertainty of finding an available bike was even higher when an e-bike was involved. In these cases, additional factors such as e-bike maintenance or e-bike batteries were also drained as uncertain factors added to the pure bike availability issue. On the other hand, the satisfaction when bikes (either conventional or electric) were available was significant, providing relief from the competitive rush-hour environment *"I feel a rush of relief when I see plenty of bikes available."* (P02). In that sense, most participants expressed that the real-time availability data, provided through apps or digital displays indicating the available bicycles at stations, alleviated much of the uncertainty associated with approaching a potentially empty dock station, although the displayed information was not always totally reliable, especially concerning the mechanical conditions of the bikes.

4.1.2. Station infrastructure

At this pre-stage of the ride, a lot of participants also discussed the degree of separation of the docked bike-sharing stations from motorised traffic. Generally, stations located at the same level as the street, with no separation and parallel to high-volume lanes were considered the least safe due to the lack of physical barriers and the proximity to fast-moving vehicles. Most of the time, the high-risk perception originated from the impossibility of manoeuvring safely when undocking bikes, particularly during peak hours. However, stations at street level that offered a safe pickup were still preferred over those on the sidewalk, as they facilitated a smoother start to cycling, especially when close to a cycling lane. When basic safety conditions were met, some participants noted this could be a mechanism to help pacify streets: *"[Locating stations at a street level] helps in pacifying the city. Drivers approaching see people moving. In the end, public space and the roadway is a space that we have to share."* (P08). Additionally, compared to stations located on the sidewalk, some participants preferred stations at street level but positioned in chamfers (i.e., the truncation of a building's corner, creating a 45-degree angled edge at street intersections). Although they acknowledged that this design would not entirely prevent a vehicle from veering into the station, this location provided participants with a higher feeling of safety. Furthermore, also related to the station design but more on a personal security level, some women expressed concerns about the degree of lighting at docked stations. From the interviewees' words, these concerns were linked to feelings of fear and were particularly present early in the morning and late at night.

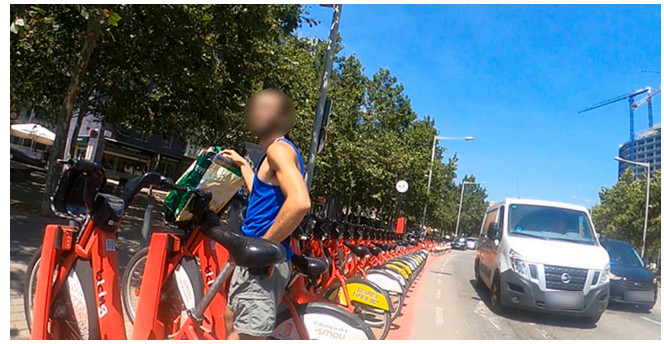

Image 2. Example of a docking station perceived as unsafe (source: author's own).

4.2. The ride

The cycling experience of moving through the urban environment and making real-time decisions was found to generate the most content and emotional responses from participants. Therefore, it was identified as the core stage of the bike-sharing experience (Fig. 3). Various environmental aspects were identified as crucial in explaining the riding stage of bike-sharing experience. Within the ride, safety emerged as a predominant concern, mentioned by all participants during the interviews. The content analysis revealed that perceptions of safety, which were mostly linked to speed differentials with actors in their surroundings, were at the same time influenced by the typology of *cycling infrastructure* and the *connectivity* within the cycling network, leading us to classify these as 'essential' themes. The physical features of the shared bikes, tagged as *equipment*, also appeared as a relevant modulator on how users experienced safety during the ride, although to a lesser extent.

4.2.1. Safety

During the interviews, safety concerns were most likely to appear when participants faced situations of clear speed difference with other actors of the space. In fact, although municipal rules allow bicycles to ride within the road, none of our participants ever chose to ride through the roadway. As P16 stated *"[…] Riding with the cars is hard because they go very fast and complain a lot"*. In that sense, all participants agreed in reporting significant discomfort and a higher sense of danger and risk when navigating in close contact with heavy traffic. This concern was amplified when cars were allowed to turn, especially if approaching from behind, as participants often felt uncertain about whether the drivers have noticed them. *"What I complain about is the amount of interference that exists between cars and bicycles, especially when cars are turning, making it difficult to feel safe"* (P06). Interestingly, the perceived risk of merging with traffic was so significant that, rather than cycling on the roadway, some participants reported opting to ride on sidewalks -which is not allowed by municipal rules- even though they were aware this choice could create risks or inconveniences for pedestrians. This highlights the extent of their discomfort with vehicular traffic and a preference for spaces perceived as safer, despite the potential for conflict with foot traffic.

Image 3. Participant navigating the sidewalk to avoid heavy traffic on the roadway (source: author's own).

In fact, interactions with pedestrians also represented another safety issue for most of the participants, although different in nature. While generally perceived as safer compared to navigating alongside cars, the slower speeds and movements of foot traffic presented concerns in spaces such as shared paths or crosswalks. This sentiment was summarized by P15, who mentioned, "*I like seeing pedestrians around as it feels safer than being near cars, but I prefer not to share the same space with them*". This statement reflects a common sentiment among cyclists: appreciating the presence of pedestrians for the sense of safety they bring to the urban environment, yet recognizing the complexities and potential safety issues that arise when directly sharing the same physical space or being in too close contact with them. Some participants discussed that the presence of inattentive pedestrians was particularly dangerous in two-way cycling spaces. Despite being designated bicycle space, potential pedestrians' distractions forced them to cycle with extra caution in those ecosystems.

A few participants also mentioned how they disliked e-scooters, especially in narrow bike lanes, where their unpredictable behaviour and different pace created complex and confusing dynamics. This issue became particularly noticeable in uphill bike lanes, where the speed differential is particularly large. As one participant riding a conventional shared bike put it: *"In uphill bike lanes, the varying speeds are especially large. You have one user going at 10 km/h and another at 25 km/h. Sharing space with such different speeds either slows everyone down or creates dangerous situations"* (P08). Additionally, few participants compared the behaviour of some e-scooter users with that of certain motorbike riders. They noted similarities in their opportunistic manoeuvrability, practices that often led to unpredictability and safety concerns. Few of them also complained regarding motorbikes occupying bike lanes in specific situations, such as in traffic lights, a practice not only posing significant safety risks for the totality of bike lanes users but also which violates traffic norms.

4.2.2. Cycling infrastructure

As a result, almost all participants expressed a clear preference for cycling within designated spaces over sharing space with other users. The heightened perceived risk and aversion associated with riding alongside high-speed traffic -particularly when private motorised vehicles, such as motorbikes, and especially cars, passed in close proximity) was greatly reduced when cycling on separated facilities. In dense urban environments with high volumes of motorised traffic, where fully isolated bike lanes may be challenging to implement, some participants expressed a preference for cycling areas adjacent to bus or taxi lanes, rather than alongside lanes used by motorbikes or cars. As articulated by P15, bike-sharing users may perceive a lower level of risk and more predictable traffic patterns when riding near larger yet slower-moving vehicles, such as buses and taxis, compared to the more unpredictable and faster-moving motorbikes and cars: *"Having a parallel exclusive lane for bus-taxi and not the normal street with cars I find it safer and easier to travel. Knowing that the only thing I have beside me is a bus or a taxi, which seem to have more respect for the bicycle, I find it easier to come this way"*. Overall, almost all participants expressed a strong preference for true physical separation, such as bollards or barriers, although cycling tracks separated from traffic by a change in elevation, such as curbs, for instance, were also considered acceptable.

Image 4. Participant riding close by an exclusive bus-taxi lane (source: author's own).

Additionally, a lot of participants mentioned the width of the cycling lane as a characteristic influencing their bike-sharing experience. During the mobile interviews, a lot of participants agreed that wider lanes enhanced a safer and more comfortable experience. Especially in uphill lanes, where speed conflicts became more present, several participants particularly mentioned that wide lanes felt more comfortable, as they enabled safer overtaking, counterposed to narrow lanes, more associated with conflicts and risk of accidents. *"It's not just my perception, they are really dangerous situations because the width is actually insufficient, and people still try to overtake... I have seen others fall while trying to overtake in narrow lanes."* (P08). The width of the cycling space was considered especially important for several participants in the specific case of two-way cycling lanes. In fact, the directionality of the lane also emerged as a crucial issue. Some participants mentioned that one-way lanes reduced the complexity of interactions with other cyclists and minimized the risk of collisions, especially in intersections, hereby enhancing the overall cycling experience for bike-sharing users.

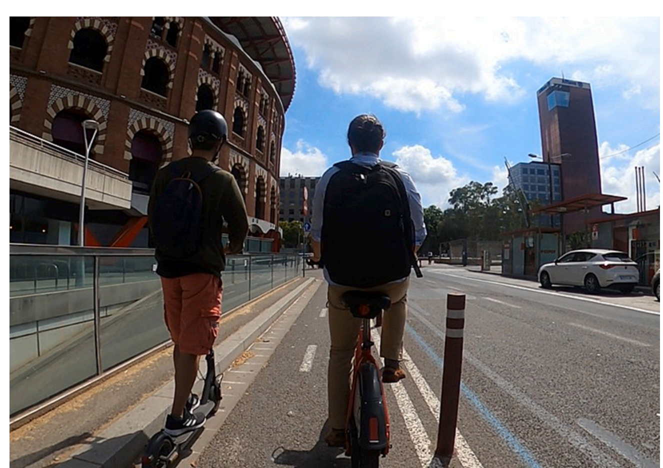

Image 5. Example of narrow and bidirectional bike lane where speed and space conflicts with other bike lane actors become evident (source: author's own).

4.2.3. Cycle network connectivity

A lot of participants pointed out that the continuity of bike lanes plays a critical role in their route experience. They particularly disliked instances where bike lanes were either missing or suddenly ended, or situations where the lanes unpredictably shifted from the road to the sidewalk, or from the right to the left side of the road. This lack of consistency not only disrupted their trip but also introduced elements of confusion and discomfort. During the interviews, it was sometimes observed that when facing less intuitive or consistent infrastructure, participants were more likely to engage in reckless behaviour, compromising in turn their feeling of security. This was clearly reflected in P04 words: "*You don't really know where to go, so you just try to find a way, but it ends up feeling unsafe*". In addition, a few participants highlighted the value of direct routes within the bike lane network. They noted that while safety is their primary concern, the efficiency of reaching their destination without unnecessary detours or interruptions is equally important, particularly for those using bike-sharing for daily commutes or time-sensitive travels.

Image 6. Example of a cycle lane shifting from the right to left side of the road (source: author's own).

This ability to easily navigate through the city was not only a matter of physical supply but also heavily dependent on effective signalling and wayfinding. Some participants emphasized the crucial role that clear signage plays in enhancing their cycling experience. They noted that well-marked bike paths and clear directional signs not only aid in efficient navigation but also significantly contribute to their sense of safety. Instances of poor or absent signage were often cited as a major concern, leading to confusion and a sense of vulnerability, especially in unfamiliar areas. In fact, participants P07, P10 and P17, who did not regularly incorporate cycling into their mobility strategy, confessed only using bike-sharing when properly knowing the way. As distilled from P10 words, this can easily deter some of them from using bikes for potential trips to unknown destinations: *"When I'm unsure about the route, I hesitate to use the bike, especially if it's somewhere I haven't been before"*.

4.2.4. Equipment design

A lot of participants highlighted the heaviness of the shared bicycles as a factor compromising their manoeuvrability and influencing their overall experience. They commented on the additional physical effort required to manoeuvre these bikes, with some noting it made riding difficult and discouraged more regular use of the bike-sharing service. Some older participants, in particular, emphasized their reliance on electric-assisted bikes, and suggested that there should be more of those bikes available. For instance, P06 stated, "*I need an electric bike. I am 60 already*". While another facing chronical knee injury said, "*If I don't find an electric bike, most of the time I'd just rather take the bus.*" (P10). The physical demand of riding a shared bike was also mentioned by some participants owning a private bicycle. P14, a young participant who commuted uphill until a bus stop before continuing by bus, remarked, "*It's a workout, especially on uphill routes. The bikes are sturdy but definitely heavier than my private bicycle*". Similarly, P08 admitted to modify her route when an electric-assisted bike wasn't available for her uphill ride commute home, saying she would cycle part of the way and walk the rest.

Beyond the issue of heaviness, other functionality challenges of shared bicycles further influenced participants' bike-sharing experiences. Some participants, especially those who owned a private bicycle, mentioned sensitivity to design and functionality issues, in particular regarding technical issues such as brakes responsiveness or seat adjustments. P01, for instance, described a common challenge encountered when using a shared bike: "*Yesterday I took an electric that the brakes didn't work well. With your bike you know exactly how to brake, you control everything. And with Bicing, each bike is a world. You always have that point where you have to raise and lower the seat [...] and if the brakes don't work well, it's a bit awkward"*. These challenges not only often required adaptability and patience on the part of the participants, as reflected in another comment, *"Sometimes, I have to stop and adjust the seat or handlebars. It's part of the experience, though it can be a bit frustrating at times"*, but also influenced their perception of safety. Additionally, a few participants identified family-related barriers to using bike-sharing systems, noting that the bicycles lack provisions for carrying small children, which limits their usability for families.

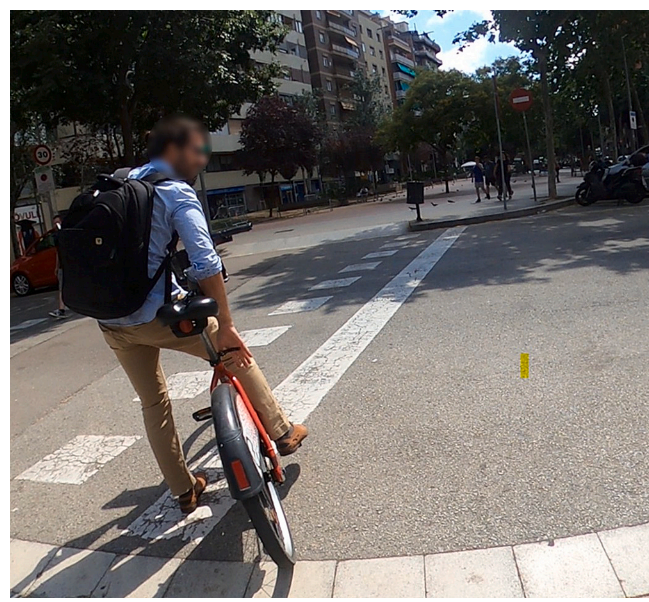

Image 7. Participant adjusting the bike seat during the ride (source: author's own)

4.3. Arrival at destination and parking

The last part of the trip was also surrounded by an aura of uncertainty. In this case, the feeling of uncertainty and confusion seemed to arise from the ability of participants to find and reach a docked station, especially when performing an unknown route. However, the concern that was judged to be most important was related to parking space availability once at destination.

4.3.1. Parking availability

Some participants mentioned that experiencing difficulties when trying to park the bike could lead to frustration. According to some of them, finding a free docking space during rush hours could be as challenging as finding a bike, and stated that successfully docking a bike brought them a sense of accomplishment and relief. This was particularly common in those trips ending next by the city beach zone, both due to the topography of the city and, especially, to the season of the year when the interviews were performed. Therefore, compared to the number of participants who mentioned uncertainty related to the picking-up stage, space availability at destination was judged to be less an intense concern for the participants. At the same time, however, a lot of participants mentioned a relief from not having to worry about bike theft. In a city where bike theft is a major concern (Sax and Honey-Rosés, 2023), the convenience of not having to secure a personal bike against robberies was mentioned as something highly valued. *"Parking the bike in a dock and just walking away without worries is always a relief"* stated P08. In fact, almost all participants owning a private bicycle mentioned that the decision to bike share in front of using their private bicycle was subjected to the ease to park the bicycle safely at destination. Additionally, in a densely populated city with limited living space, the lack of necessity to carry the personal bicycle upstairs and store it in tiny apartments appeared to be a significant relief and a major enhancer for the usage of the bike-sharing systems, as reflected in P08's words: *"I have an electric bike too and it's great, the thing is I have to lift it on the elevator and it's a bit uncomfortable"*.

4.3.2. Station accessibility

Some participants referred to the moment of accessing the bike station at the end of the trip. Effective wayfinding aids, like well-placed signage indicating how to reach the closest station, were mentioned by a few participants as elements the city was missing and that could easily enhance their experience. Although participants expressed a strong preference for not having to check their phones during the ride, they acknowledged the necessity of doing so due to the lack of alternative wayfinding options. At this final stage, some participants also emphasized the importance of accessing docking stations via bike lanes, as P06 stated: "*One thing I don't understand is that some docking stations are located where there is no cycle lane. I don't like and I don't understand why they are disconnected from the cycling network.*" Generally, stations connected directly to bike lanes, with a clear and safe path free from motorised traffic or pedestrian crowds, were considered ideal. This configuration was preferred as it was perceived to reduce the risk of incidents and facilitate a smoother transition from cycling to walking.

5. Discussion and conclusions

This study explored the external factors that may influence users' perceptions and experiences of docked bike-sharing systems. Using mobile interviews, we were able to grasp contextualised information indicating that the experience of docked bike-sharing in a dense urban environment such as Barcelona extends beyond simply riding a shared bicycle and differs significantly from riding a private bicycle. Naturally, while a great part of the experience is significantly influenced by traffic safety during this central riding stage of the trip, our findings reveal the critical influence of other trip moments, such as bicycle pick-up and drop-off, which are often overlooked in cycling research and policy. This suggests that strategies aiming to promote docked bike-sharing usage should keep on investing in the provision of safe cycling environments, mainly through well-separated cycling infrastructure and improved cycling network connectivity. However, at the same time, this highlights that efforts should also focus on implementing better solutions and designs for docked stations, which still hold significant potential to improve the overall bike-sharing experience.

Our finding that traffic safety is a crucial issue for individuals using docked bike-sharing systems is consistent with findings of prior research on urban cycling (Christ et al., 2023; Yen et al., 2014). These studies suggest that traffic safety functions as the central factor mediating the relationships between external elements and the act of cycling. In fact, recent research using latent variables has highlighted the relative greater importance of safety as a key component when bike-sharing users evaluate cycling facilities. This contrasts with previous research which pointed to attitudes towards bike-sharing as playing a more influential role in shaping individual cycling perceptions and preferences (Rossetti et al., 2018). However, this concern for traffic safety also exposes a paradox: despite bike-sharing users being statistically underrepresented in bicycle accident data and tending to sustain less severe injuries compared to private cyclists, the perceived lack of safety persists. In a study conducted in Italy, Marín Puchades et al. (2018) examined data on regular cycling and bike-sharing activities, along with related collisions, to assess injury rates. They found that collision and injury rates for bike-sharing were lower than those for personal cycling, attributing this to bike-sharing rider behaviour and the design of bike-sharing bicycles. This contradiction may stem from the unique characteristics of shared bicycles -heavier frames and limited manoeuvrability- that, while designed to enhance stability and limit speed, thus reducing collision risk, actually specifically cause the perception that bike-sharing bicycles are of lower quality, which ironically contributes to lower levels of perceived safety.

Image 8. To the left, example of docked station disconnected from the cycling network. To the right, example of docked station connected to the cycling network (source: author's own).

Our findings also uncover traffic safety to be closely interlinked with cycling infrastructure and street connectivity, findings already noticed by literature on private urban cycling. Participants in our study exhibited a preference for designated and wide cycling space, ideally separated from motorised traffic, particularly on narrow streets with heavy and speeding traffic. This is consistent with previous studies which uncovered that the risk of injury for cyclists is significantly reduced on paved paths separated from traffic by a physical barrier. These studies have quantitively shown a lower number in terms of collisions and qualitatively indicated less severe cycling injuries compared to cycling on major streets with parked cars and no designated cycling space (Cripton et al., 2015; Teschke et al., 2012). This is particularly important in the context of bike-sharing, where cyclists with varying levels of skill and frequency of use share the same space with other road users exhibiting more consistent or uniform travel behaviours. Consistent with findings in Ni et al. (2024), the ability to overtake or be overtaken without compromising safety or encroaching on the space of other road users added not only a layer of comfort but also of functionality to the participants. Additionally, another factor that influenced participants' experiences was when the cycle lane ended. However, unlike studies on urban cycling that observed cyclists merging with traffic due to infrastructure shortages (Mayers and Glover, 2021), participants in our study avoided this option opting instead for sidewalks despite acknowledging the resulting risks to pedestrians. This behaviour is clearly linked to the heavy and difficult-to-manoeuvre physical characteristics of shared bicycles, which could make navigating mixed-traffic environments particularly challenging and dangerous.

A notable and often underestimated aspect revealed by this study is the significant role of docked stations in shaping the bike-sharing experience. While larger station capacities are generally associated with improved service access (Hu et al., 2021; Wu et al., 2021), our findings highlight significant supply shortages during peak demand at high-capacity stations, particularly near major mobility hubs. On the one side, this finding supports previous conclusions in the US and China, where a positive association between the number of docks in a station and bike-sharing usage was observed (Hu et al., 2021; Wu et al., 2021; Y. Zhang et al., 2017). At the same time, however, it also challenges the assumption that station size alone guarantees system reliability (Zhu et al., 2022). Instead, particularly in cities with dense, multi-modal transportation networks like Barcelona, for public docked bicycle-sharing systems to generate confidence, create loyalty among its users and be able to seduce new ones, our results emphasize the need for more dynamic redistribution strategies that anticipate asymmetric travel patterns (Mohammed, 2017), especially in specific typologies of station. While gamification strategies have been suggested as powerful and alternative solutions to encourage system re-balancing and redistribution (Ahram and Falcão, 2020; Johnson and Wu, 2021), our participants' limited awareness and engagement with already existing incentives reveal their current ineffectiveness and point to other strategies for system optimization.

The significance of docked stations in the overall bike-sharing experience extends beyond station capacity and turnover ratios. In particular, the design of the stations emerged as another critical dimension influencing user satisfaction and safety perceptions. Participants expressed concerns about stations located in close proximity to motorised traffic, which were perceived as unsafe; and stations on sidewalks, which were viewed as inconvenient for pedestrians. These findings resonate with prior research on station placement (Hurtubia et al., 2021) but expand the discussion to highlight the importance of micro-design features such as designated buffer zones for bicycle pick-up and drop-off, well-lit environments, and clear signage. While we acknowledge that placing docked stations can be a strategy to reclaim space from motorised vehicles, our findings show that, in order to ensure a successful transition towards a more sustainable mobility paradigm, this should not compromise users' sense of security during the transition from pedestrian to cyclist, and vice-versa. Measures could include, for instance, implementing a maximum speed limit of 10 km/h on adjacent lanes or installing speed bumps just before vehicles approach the station area to reduce motor vehicle speeds. Importantly, our study adds a gendered dimension to this issue, echoing Pearson et al. (2023), as women expressed heightened concerns about poor or absent lighting at stations, specially at trip origins, potentially deterring bike usage or altering travel patterns. Clear and visible signage when approaching or locating docked stations was also deemed essential according to several participants, especially for users with lower frequency of use and in order to improve the user experience within trips taking place out of their well-known areas, findings that perfectly align with those in van Lierop et al. (2020). Additionally, being free from securing and maintaining their bikes seemed to have a beneficial influence on participants' satisfaction with the bike-sharing decision.

As a primary limitation, it is important to highlight that our study focuses basically on the external factors influencing travel behaviour at a street level and does not address broader-scale patterns. Nevertheless, the ability of bike-sharing systems to offer flexible, ad-hoc mobility strategies provides users with a sense of autonomy that was often pointed out by the participants. Consistent with findings in other contexts (Fan et al., 2019), being able to spontaneously choose or change routes based on real traffic conditions or personal preferences was highly valued by participants. However, our findings also suggest that such flexibility is limited by station supply reliability, which can diminish the perceived benefits of the system. Similarly, in line with multicity level studies in the U.S. (Hosford et al., 2019), bike-sharing was found to foster broader cycling habits among some participants, positioning bike-sharing schemes as a gateway to attract more non-cyclists into cycling. However, these benefits may be undermined if users' perceive bike-sharing stations and facilities as unsafe, infrastructure quality as inconsistent, or shared bikes as mechanically unreliable. A second limitation lies in its qualitative design, which does not allow for the establishment of quantitative relationships between environmental factors and bike-sharing practices. The associations identified through our inductively derived model should therefore be regarded as a foundation for developing specific hypotheses to be tested in future quantitative research. Finally, the study was conducted in Barcelona, a city distinguished by its high residential density and compact urban form. These contextual factors may restrict the generalizability of the findings to cities with different spatial and mobility characteristics.

To conclude, we recommend that city experts and city planning departments take into consideration the importance of how cycling space is perceived by all different groups of cyclists if they wish to increase cycling participation and create more equitable cities. Our findings suggest that objective safety outcomes alone are insufficient; subjective perceptions of safety, shaped by infrastructure and bicycle design, warrant equal attention. Based on participants' experiences, cycling policy should emphasize on improving safety along routes which have been identified by bike-sharing users as unsafe. Features such as consistency among cycling paths, dedicated cycling infrastructures or complex urban traffic are critical to encourage more participation in cycling. Additionally, elements as poor signage or confusing wayfinding systems, which might be manageable for cyclists driving their own bike, are critical for bike-sharing users. Ignoring them and their relevance may be slowing down the popularity of bike-sharing and its potential as a gateway to drive urban travellers into the cycling culture for transportation (Fishman, 2016; Nikitas et al., 2014). At the same time, importantly, urban planners should consider the role of docked stations, spaces that appear to be critical for the evaluation of the whole bike-sharing experience. The trustworthiness of a bike-sharing system depends on the certainty that users will find a bike when they need it, highlighting the need for consistent bike availability and effective redistribution strategies. Additionally, the design of docked stations plays a key role in shaping users' satisfaction, suggesting that carefully crafted station layouts can alleviate concerns and foster a positive user experience. In line with Jeon and Woo (2024), we believe that creating streetscape environments around stations that offer improved visibility and responsiveness will contribute to the transformation of urban areas into safer environments for cycling, enhancing at the same time everyone's safety perception (Hurtubia et al., 2021). Improving satisfaction it is demonstrated to be a powerful tool to increase bike-sharing usage, not only contributing to user retention but also encouraging word-of-mouth promotion (Xue Xingjian et al., 2022). Therefore, by paying attention to docked stations design and dynamics, policy makers and practitioners will most likely be able to keep current users loyal and, at the same time, attract new users (Mayers and Glover, 2021).

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CRediT authorship contribution statement

Oriol Roig-Costa: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Carme Miralles-Guasch:** Supervision, Project administration, Funding acquisition. **Oriol Marquet:** Writing – review & editing, Validation, Supervision.

Declaration of competing interest

The authors declare no conflict of interest.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jtrangeo.2025.104184.

Data availability

The authors do not have permission to share data.

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