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# The emergence of micromobility in Barcelona: exploring the behavioural, social and environmental dimensions of new urban modes

**Oriol Roig Costa**

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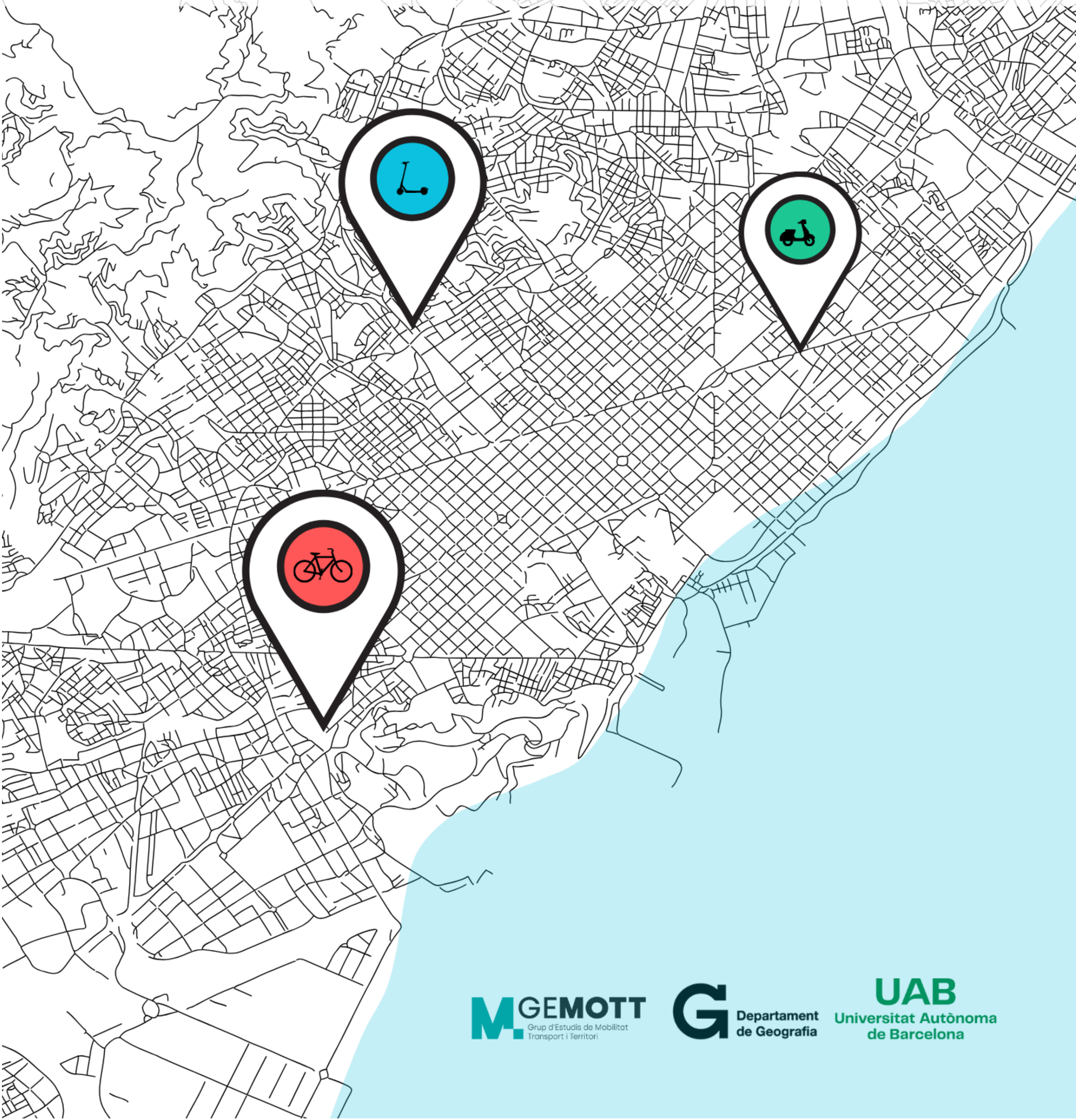

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Grup d'Estudis de Mobilitat Transport i Territori
Departament de Geografia
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Tesi doctoral

# THE EMERGENCE OF MICROMOBILITY IN BARCELONA: EXPLORING THE BEHAVIOURAL, SOCIAL AND ENVIRONMENTAL DIMENSIONS OF NEW URBAN MODES


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*També pots venir si vols*

*T'esperem, hi ha lloc per tots*

*El temps no conta, ni l'espai*

*Qualsevol nit pot sortir el sol*

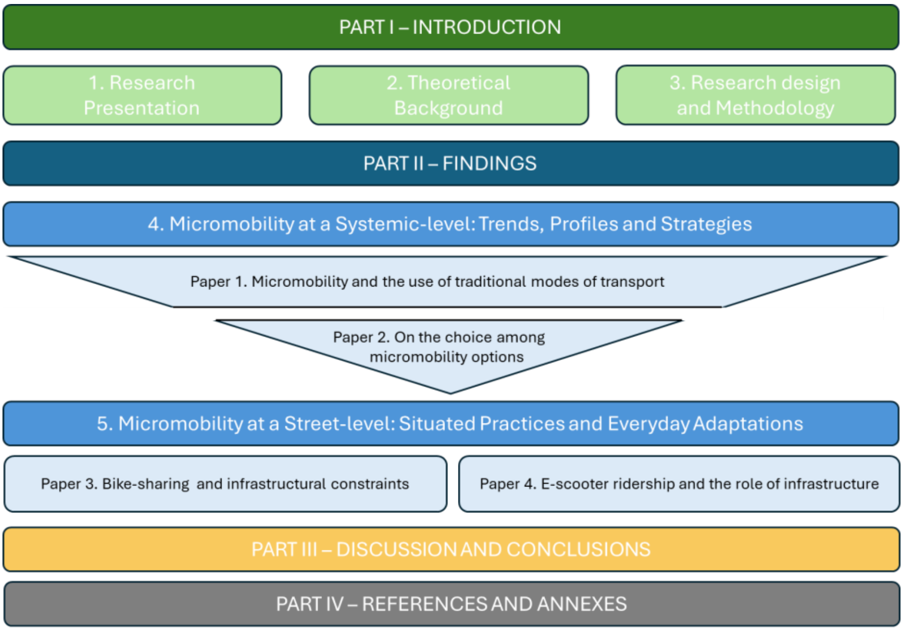
Jaume Sisa, *Qualsevol nit pot sortir el sol*

# Preface

This thesis adheres to the guidelines set forth by the Academic Committee of the Doctoral Program (CAPD) within the Department of Geography at Universitat Autònoma de Barcelona (UAB), as outlined in RD 99/2011 and the transitional provision ratified by CAP on October 13th, 2022. In accordance with the specific stipulations of RD 99/2011, all article-based dissertations must comprise a minimum of three scientific contributions authored by the candidate, either published in academic journals or in the form of books or book chapters, among other formats. These contributions must be either published or at least accepted prior to submission. Based on this regulation, this dissertation is structured as follows, and as presented in Figure 1:

- Part I comprises three chapters that introduces the research, establishes a broad theoretical framework, and presents the research design and the methodology.
- Part II presents the core of the thesis, findings which are derived from four studies, three of them published in academic journals and a fourth one in editorial revisions.
- Part III encompasses the discussion and conclusions.
- Part IV contains the references and any annexes.

Figure 1. Dissertation structure.




Source: own elaboration

This doctoral thesis is founded upon four scientific articles. To date, three of these papers have been published and one of them is currently under revision. The bibliographical references of each of the publications, as well as the main indicators of academic impact according to the Journal Citation Report® are detailed below:

1) **Roig-Costa, O.**, Marquet, O., Arranz-López, A., Miralles-Guasch, C., & Van Acker, V. (2024). Understanding multimodal mobility patterns of micromobility users in urban environments: insights from Barcelona. Transportation, 1-29. https://doi.org/10.1007/s11116-024-10531-3 JCR (2023): Impact Factor (IF) = 3,5, Journal Rank = **Q1** (Civil Engineering); **Q2** (Transportation).

2) **Roig-Costa, O.**, Miralles-Guasch, C., & Marquet, O. (2024). Shared bikes vs. private e-scooters. Understanding patterns of use and demand in a policy-constrained micromobility environment. Transport policy, 146, 116-125. https://doi.org/10.1016/j.tranpol.2023.11.010 JCR (2023): Impact Factor (IF) = **6,5**, Journal Rank = **Q1** (Transportation; Economics).

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4) **Roig-Costa, O.**, Miralles-Guasch, C., & Marquet, O. (2025). Affective geographies of e-scooter travel: Infrastructure, emotions, and adaptive strategies. Emotion, Space and Society. Second revisions, first sent to the journal on February the 3rd, 2025. JCR (2023): Impact Factor (IF) = 1,9, Journal Rank = **Q1** (Social Sciences, Interdisciplinary); **Q2** (Geography).

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- **New mobility in the city (NEWMOB).** 19S01360 -006. Convocatòria Pla Barcelona Ciencia 2019. Institut de Cultura, Ajuntament de Barcelona. Period: 01/01/2020- 31/01/2022. Lead researcher: Dr. Oriol Marquet (Universitat Autònoma de Barcelona).
- **Inclusiva, sostenible, saludable i resilient. La mobilitat i la ciutat en l'escenari postpandèmia (PANDÈMIES)**. 2020 PANDE 00023. Convocatòria Replegar-se per créixer: l'impacte de les pandèmies en un món sense fronteres visibles (Pandèmies 2020). AGAUR, Generalitat de Catalunya. Period: 14/05/2021-13/11/2022. Lead researcher: Dr. Carme Miralles-Guasch (Universitat Autònoma
- **La transición ecológica en la movilidad y el transporte. El papel de la proximidad urbana (ECOMOV).** TED2021-129280B-I00. Convocatoria Proyectos estratégicos orientados transición ecológica y transición digital 2021. Ministerio de Ciencia, Innovación y Universidades. Period: 01/12/2022 – 30/11/2024. Lead researchers: Dr. Carme Miralles-Guasch and Dr. Oriol Marquet (Universitat Autònoma de Barcelona).
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# Agraïments

Aquesta tesi l'he escrit des del privilegi de saber-me rodejat d'un entorn que sempre ha remat a favor. Vull aprofitar aquest espai per agrair a les persones que el conformen per haver contribuït, cadascuna a la seva manera i des del seu lloc, a que aquest trajecte no només fos possible, sinó que també fos enriquidor i carregat de sentit.

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# Abstract

Technological innovation has long played a central role in shaping the way societies move. From the invention of the wheel to the expansion of railways and the development of internal combustion engine, each major breakthrough has reconfigured mobility systems and the organization of everyday life throughout history. Today, micromobility is often presented as the latest disruptive force in urban transport, celebrated for its potential to reduce emissions, reclaim public space, and revolutionise short-distance travel. However, much of this promise remains speculative. While e-scooters, shared bikes, and other lightweight vehicles have proliferated in cities worldwide, their actual impact on mobility systems and climate goals is still unclear. In this context, it is important to temper the prevailing techno-optimism that frames innovation as a self-evident solution to the climate emergency. Rather than assuming that micromobility will automatically deliver sustainability, it is crucial to examine how it is adopted, by whom, under what conditions, and with what unintended consequences.

Against this backdrop, following a multi-scalar approach, this thesis investigates how the emergence of micromobility interacts with, challenges, or integrates into the established mobility order. At the macro level, the dissertation examines general patterns and emerging trends in micromobility user behaviour, exploring the extent to which it constitutes a truly disruptive innovation, and whether it holds the capacity to foster meaningful environmental improvements, social inclusion, or sustained changes in travel habits. At the micro level, the thesis explores how individuals engage with space as they move around the city, capturing street-level dynamics and the affective dimensions of travel, dynamics often not considered in the analysis of conventional transportation. This multi-scalar perspective enables a more comprehensive understanding of how micromobility disrupts or consolidates

existing transport logics, not only in terms of modal shift or habit formation, but also in how mobility is experienced, negotiated, and made sense of on a daily basis.

The results suggest that its transformative potential of micromobility, whether environmental, social, or behavioural, remains modest and highly contingent on contextual conditions. Through the four case studies, which explore different facets of micromobility within Barcelona, it is shown that the adoption patterns and user experiences appear to be shaped by local regulatory frameworks, urban morphology, existing modal distributions, and broader transport cultures. These locally rooted dynamics not only condition the role that micromobility can play, but also reveal the limitations of treating it as a universally applicable or inherently sustainable solution.

## Resum

La innovació tecnològica ha jugat durant molt de temps un paper central en la configuració de la manera com es mouen les societats. Des de la invenció de la roda fins a l'expansió dels ferrocarrils i el desenvolupament del motor de combustió interna, cada gran avenç ha reconfigurat els sistemes de mobilitat i l'organització de la vida quotidiana al llarg de la història. A dia d'avui, la micromobilitat es presenta sovint com la darrera força disruptiva en el transport urbà, celebrada pel seu potencial per reduir emissions, recuperar l'espai públic i revolucionar els viatges de curta distància. Tot i això, gran part d'aquesta promesa continua sent especulativa. Si bé els patinets elèctrics, les bicicletes compartides i altres vehicles lleugers han proliferat a les ciutats de tot el món, el seu impacte real en els sistemes de mobilitat i els objectius climàtics encara no està clar. En aquest context, és important moderar el tecno-optimisme predominant que emmarca la innovació com una solució evident a l'emergència climàtica. En lloc de suposar que la micromobilitat proporcionarà sostenibilitat automàticament, és crucial examinar com s'adopta, qui ho fa, en quines condicions i amb quines conseqüències no desitjades.

Amb aquest rerefons, seguint un enfocament multi-escalar, aquesta tesi investiga com l'aparició de la micromobilitat interactua, desafia o s'integra amb l'ordre de mobilitat establert. A nivell macro, la tesi examina els patrons generals i les tendències emergents en el comportament dels usuaris de micromobilitat, explorant fins a quin punt constitueix una innovació veritablement disruptiva i si té la capacitat de fomentar millores ambientals significatives, inclusió social o canvis sostinguts en els hàbits de viatge. A nivell micro, la tesi explora com els individus es relacionen amb l'espai mentre es desplacen per la ciutat, capturant les dinàmiques a nivell de carrer i les dimensions afectives del viatge, dinàmiques sovint no considerades en l'anàlisi del transport convencional. Aquesta perspectiva multi-escalar permet una

comprensió més completa de com la micromobilitat interromp o consolida les lògiques de transport existents, no només en termes de canvi modal o formació d'hàbits, sinó també en com s'experimenta, es negocia i es dona sentit a la mobilitat diàriament.

Els resultats suggereixen que el potencial transformador de la micromobilitat, ja sigui ambiental, social o conductual, continua sent modest i molt contingent en les condicions contextuals. A través dels quatre estudis de cas, que exploren diferents facetes de la micromobilitat a Barcelona, es mostra que els patrons d'adopció i les experiències dels usuaris semblen estar modelats pels marcs reguladors locals, la morfologia urbana, les distribucions modals existents i les cultures de transport. Aquestes dinàmiques arrelades localment no només condicionen el paper que pot tenir la micromobilitat, sinó que també revelen les limitacions de tractar-la com una solució universalment aplicable o inherentment sostenible.

# Contents

Preface ........ vii
Agraïments ........ xi
Abstract ........ xviii
Resum ........ xx
List of figures ........ xxviiii
List of tables ........ xxxix
List of maps ........ xxviiix

PART I. INTRODUCTION ........ 3
1. Research presentation ........ 5
1.1. General context ........ 5
1.2. Research questions and hypothesis ........ 8
1.3. Overview of the thesis ........ 11
2. Theoretical framework ........ 15
2.1. The irruption of micromobility: taxonomy and definition ........ 15
2.2. Theoretical frameworks on the irruption of technological innovations ........ 22
2.2.1. Sociotechnical Transitions ........ 23
2.2.2. Innovation Diffusion Theory ........ 25
2.2.3. Infrastructure Studies ........ 26
2.2.4. Social Practice Theory ........ 27
2.3. Adoption of a multilevel framework to micromobility travel behaviour ........ 29
2.3.1. Normative dimension ........ 30
2.3.2. Physiscal dimension ........ 33
2.3.3. Territorial dimension ........ 34
2.3.4. Individual dimension ........ 35
3. Research design and methodology ........ 41

3.1. General reseacrh design ..... 41
3.2. Characterization of the study area ..... 43
3.2.1. Barcelona ..... 43
3.2.2. Barcelona's mobility patterns ..... 44
3.2.3. Barcelona's micromobility ecosystem ..... 45
3.3. Data sources ..... 48
3.3.1. Micromobility survey ..... 48
3.3.2. Interviews ..... 49
3.4. Analysis techniques ..... 52
3.4.1. Quantitative techniques ..... 52
3.4.2. Qualitative techniques ..... 53
3.4.3. Research ethics ..... 58
PART II. FINDINGS ..... 61
4. Micromobility at a systemic level: trends, profiles and strategies ..... 63
4.1. Understanding multimodal mobility patterns of micromobility users in urban environments. Insights from Barcelona context ..... 63
4.1.1. Introduction ..... 64
4.1.2. Literature review ..... 68
4.1.3. Methodology ..... 74
4.1.4. Results ..... 81
4.1.5. Discussion ..... 90
4.1.6. Conclusions ..... 98
4.2. Shared bikes vs. private e-scooters. Understanding patterns of use and demand in a policy-constrained micromobility environment ..... 100
4.2.1. Introduction ..... 101
4.2.2. Background ..... 103
4.2.3. Methods ..... 108
4.2.4. Results ..... 112
4.2.5. Discussion ..... 122

4.2.6. Conclusions ........................................................................ 129
5. Micromobility at a street level: situated practices and everyday adaptations.…………………………………………………………………...131
5.1. Unpacking the docked bike-sharing experience. A bike-along study on the infrastructural constraints and determinants of everyday bike-sharing use………….. ........................................................................................ 131
5.1.1. Introduction ........................................................................ 132
5.1.2. Background ........................................................................ 134
5.1.3. Method ........................................................................ 141
5.1.4. Results ........................................................................ 147
5.1.5. Discussion and conclusions .................................................. 163
5.2. Affective geographies of e-scooter travel: Infrastructure, emotions, and adaptive strategies ........................................................................ 170
5.1.1. Introduction ........................................................................ 171
5.1.2. Background ........................................................................ 174
5.1.3. Methods ........................................................................ 179
5.1.4. Findings ........................................................................ 186
5.1.5. Concluding remarks ............................................................ 206
PART III. DISCUSION AND CONCLUSION ........................................ 211
6. Discussion ........................................................................ 213
6.1. Discusion of the main findings .................................................. 213
6.2. General conclusion ........................................................................ 228
7. Final reflections ........................................................................ 231
7.1. Strengths and limitations ........................................................................ 231
7.2. Future research ........................................................................ 234
7.3. Policy implications ........................................................................ 236
PART IV. REFERENCES AND ANNEXES ........................................... 239
8. References ........................................................................ 241
9. Annexes ........................................................................ 313

9.1.Letters of co-authors ........................................................................ 313
9.2.Supplementary matherials ................................................................ 315
9.1.1. Interviews conducted per interviewer per day project NEWMOB.................................................................................... 315
9.1.2. Brief questionnaire pre- mobile interviwes ............................ 315
9.1.3. Bike-sharing system users' mobile interview tracks .............. 316
9.1.4. E-scooter users' mobile interview tracks ................................ 324
10. Thesis outreach and additional activities............................................ 331
10.1. Dissemination of the thesis results ............................................. 331
10.1.1. Participation in national and international conferences ........ 331
10.1.2. Talks and presentations related to the thesis ......................... 332
10.2. Training ....................................................................................... 333
10.2.1. Attendances at conferences and seminars of interest ............ 333
10.2.2. Training activities ................................................................ 334
10.2.3. Teaching activities ............................................................... 335
10.3. Research stays ............................................................................. 336
10.4. Other related publications .......................................................... 336

## List of figures

Figure 1. Dissertation structure ..... vi
Figure 2. Proposed micromobility definition by the International Transport Forum ..... 18
Figure 3. Conceptual delimitation of micromobility modes used in this thesis, combining technical and sociological criteria ..... 22
Figure 4. A dynamic multi-level perspective on technological transitions ..... 24
Figure 5. Conceptual framework of multilevel dimensions influencing micromobility adoption and travel behaviour ..... 30
Figure 6. Multi-scale and multi-methodological research design ..... 42
Figure 7. Modal share of internal and connecting trips in Bcn ..... 45
Figure 8. Modal share of the 3 main micromobility modes in Bcn ..... 47
Figure 9. Fieldwork materials for mobile interview data collection ..... 51
Figure 10. Visual representation of the integration of discourse, visual, and spatial layers in Atlas.ti® ..... 58
Figure 11. E-scooter and BSS modal replacement scheme ..... 118
Figure 12. Change in satisfaction versus former mode of transport ..... 120
Figure 13. Public docked-shared bicycle (*Bicing*) stations and station typologies in Barcelona ..... 142
Figure 14. External aspects influencing the experience of bike-sharing. Model derived from the inductive analysis ..... 148
Figure 15. Example of a participant encountering bicycle unavailability at a station located near a major mobility hub ..... 150
Figure 16. Example of a docking station perceived as unsafe ..... 152
Figure 17. Participant navigating the sidewalk to avoid heavy traffic on the roadway ..... 154
Figure 18. Participant riding close by an exclusive bus-taxi lane ..... 156
Figure 19. Example of narrow and bidirectional bike lane where speed and space conflicts with other bike lane actors become evident ..... 157

Figure 20. Example of a cycle lane shifting from the right to left side of the road........................................................................................ 158
Figure 21. Participant adjusting the bike seat during the ride .................... 161
Figure 22. Examples of docked station (dis)connected from/to the cycling network........................................................................................ 163
Figure 23. Participant ESC01 riding through a dedicated, unidirectional, and wide bike lane ........................................................................................ 191
Figure 24. Tendencies when riding in a 30km/h bike sharrow. Above, females. Below, males........................................................................ 195
Figure 25. Female participants leaning to the right side of a bidirectional lane when crossing with another cycle lane user .............................................. 197
Figure 26. Participants foot positioning .................................................... 198
Figure 27. Participants "walking the e-scooter" facing lane discontinuity.. 199
Figure 28. Participants illegally riding the sidewalk .................................. 201
Figure 29. Participants riding counterflow and running a red traffic light.. 203
Figure 30. Participant dismounting to cross as a temporary pedestrian ...... 204
Figure 31. Affective feedback loop of e-scooter travel experience in urban environments ........................................................................................ 206

## List of tables

Table 1. Conceptual frameworks addressing technological innovation and their relevance for micromobility ........ 28
Table 2. Example of e-scooter participants behavioural riding audition....... 54
Table 3. Example of quotations and coding within the thematic analysis stage ........ 56
Table 4. Summary of the case studies in the thesis, their aims, their relationship to the research questions posed and the methodology used ...... 59
Table 5. Sociodemographic characteristics of the sample ........ 77
Table 6. Self-reported frequency of use of micromobility modes of transport (frequency in %)........ 83
Table 7. Self-reported frequency of use of other traditional modes of transport (frequency in %)........ 85
Table 8. Adjusted associations between the frequency of use of traditional modes of transportation, socioeconomic characteristics, locational variables, and clusters of micromobility travel behaviours. Multinomial logistic regression model ........ 88
Table 9. Individual and usage-related characteristics of the sample ........... 113
Table 10. Binary logit model of the probability of using a private e-scooter over using BSS in Barcelona........ 116
Table 11. Subjective assessment of satisfaction on private e-scooters and BSS........ 119
Table 12. Reasons for changing to private e-scooter and BSS, according to former transport mode........ 122
Table 13. Participants' characteristics and BSS travel related behaviour ... 146
Table 14. Participants and trips characteristics ........ 182
Table 15. Interviews conducted per interviewer per day project NEWMOB ...... 315

## List of maps

Map 1. Location of Barcelona within the Barcelona Metropolitan Region (BMR) .... 44
Map 2. Geographic distribution of survey interception points and catchment area for the EPUVMB .... 49
Map 3. Docked-shared bicycle stations and e-moped coverage area in the City of Barcelona .... 75
Map 4. Participant BSS01 trip .... 145
Map 5. Participant ESC01 trip .... 184
Map 6. Participant BSS02 trip .... 316
Map 7. Participant BSS03 trip .... 316
Map 8. Participant BSS04 trip .... 317
Map 9. Participant BSS05 trip .... 317
Map 10. Participant BSS06 trip .... 318
Map 11. Participant BSS07 trip .... 318
Map 12. Participant BSS08 trip .... 319
Map 13. Participant BSS09 trip .... 319
Map 14. Participant BSS10 trip .... 320
Map 15. Participant BSS11 trip .... 320
Map 16. Participant BSS12 trip .... 321
Map 17. Participant BSS13 trip .... 321
Map 18. Participant BSS14 trip .... 322
Map 19. Participant BSS15 trip .... 322
Map 20. Participant BSS16 trip .... 323
Map 21. Participant BSS17 trip .... 323
Map 22. Participant ESC02 trip .... 324
Map 23. Participant ESC03 trip .... 324
Map 24. Participant ESC04 trip .... 325
Map 25. Participant ESC05 trip .... 325

Map 26. Participant ESC06 trip ..................................................................... 326
Map 27. Participant ESC07 trip ..................................................................... 326
Map 28. Participant ESC08 trip ..................................................................... 327
Map 29. Participant ESC09 trip ..................................................................... 327
Map 30. Participant ESC10 trip ..................................................................... 328
Map 31. Participant ESC11 trip ..................................................................... 328
Map 32. Participant ESC12 trip ..................................................................... 329

# PART I - INTRODUCTION

# 1. Research presentation

## 1.1. General context

The climate crisis is no longer a distant threat but a condition shaping the present. Transport systems play a central role in this crisis, contributing around 24% of global energy-related $CO_2$ emissions, and remaining one of the few sectors where emissions continue to rise (International Agency for Energy, 2023). This is not simply the result of technological limitations, but mainly of policy inertia and planning choices that have historically prioritised private car use over collective and sustainable alternatives. Urban areas are where these patterns are most concentrated, and as a result, they face particular challenges. By 2050, almost 70% of the global population will live in cities (United Nations, 2018), placing enormous pressure on infrastructures that are already overstretched. In many cases, urban mobility systems will continue to reproduce social inequalities, exclude vulnerable groups, and contribute to deteriorating air quality and public health. Reimagining how we move through cities is therefore not just a question of efficiency or emissions reduction, it is a political necessity tied to questions of justice, accessibility, and the right to the city.

In this context, signs of change have begun to emerge in the urban mobility landscape, marked by the growing presence of new transport modes and services collectively referred to as micromobility. Challenging traditional patterns of travel, micromobility has rapidly gained traction in cities around the world. Due to their small size and electric propulsion, vehicles such as e-bikes and e-scooters offer a more space-efficient and lower-emission alternative to conventional modes (The International Transport Forum, 2020), while significantly occupy less space, both when parked and in motion, making them particularly suitable for urban environments where space is a limited and contested resource (Y. Zhang et al., 2023). Their integration into everyday mobility patterns is also thought to contribute to more equitable transport systems by improving access to public transport and reducing travel times for those living in areas with poorer service provision (Oeschger et al., 2020; Tzouras et al., 2024). In this sense, micromobility not only is presented as an alternative offering environmental and spatial benefits but also an option that holds the potential to mitigate certain forms of spatial inequality embedded in current transport networks (Abduljabbar et al., 2021).

However, these optimistic projections often coexist with emerging concerns. Questions have been raised about safety, unequal access, the environmental cost of vehicle production and maintenance, and the actual extent to which micromobility displaces car usage rather than replacing walking or public transport (Hollingsworth et al., 2019; Wang et al., 2022). Furthermore, the unequal distribution of shared micromobility services across urban space risks reinforcing existing mobility inequalities, privileging already well-connected areas while neglecting others (Bach et al., 2023a). These tensions point to a broader issue: while micromobility holds significant transformative potential, its integration into existing urban mobility systems is far from straightforward. Understanding its effects requires moving beyond technological determinism and engaging in the social, spatial, and behavioural dimensions that shape everyday travel. User preferences, infrastructural conditions, legal regulations, and the physical configuration of the public space all interact to influence how, where, and by whom micromobility is used. Gaining insight into how users of different transport modes share infrastructure, such as roads, cycle lanes, or pavements, what kinds of conflicts emerge from this coexistence, and which factors matter most to improve their experience, is also essential for understanding how micromobility unfolds in the urban context.

These structural challenges intersect with individual-level behaviours and perceptions, which play a pivotal role in shaping how micromobility is adopted and integrated into everyday mobility practices (Bretones & Marquet, 2022a). However, individual travel behaviours are deeply embedded in routines, habits, and social norms, making modal change a slow and complex process, shaped not only by functional considerations but also by perceptions, emotions, and values (De Witte et al., 2013). Travel decisions are rarely neutral or purely rational; they are conditioned by prior experience, cultural expectations, and the material conditions of the urban environment (Schwanen et al., 2012). Thus, promoting a shift towards more sustainable modes requires more than simply increasing the availability of alternatives: it also demands attention to how people feel, interpret, and navigate their travel options on a daily basis (Bissell, 2010; Spinney, 2009). In the case of micromobility, this means recognising that its adoption is influenced not only by its technical features, but also by how infrastructure supports or hinders its use, how regulation shapes its legitimacy, and how users perceive its safety, comfort, and social acceptability. The dynamics of micromobility use are therefore as much about the streets and policies that frame them as about the individuals who ride.

Against this backdrop, this dissertation seeks to contribute to the growing but still limited body of knowledge on micromobility by investigating how these modes are adopted and integrated into the everyday mobility strategies of individuals in Barcelona, an example of a dense and compact city. In doing so, it addresses key questions about the behavioural, infrastructural, and policy-related aspects of micromobility, aiming to shed light on the opportunities it offers as well as the challenges it poses. By adopting a multi-method and multi-scalar perspective, this research offers a grounded, context-sensitive analysis of micromobility, with the ultimate goal of informing more inclusive, effective, and sustainable urban mobility policies.

### 1.2. Research questions and hypotheses

The aim of this research is to understand the emergence of micromobility in the city of Barcelona, with particular attention to how mobility strategies are configured at the user level and the broader implications this entails. Specifically, the dissertation seeks to characterize the different user profiles and examine how these users organise their modal strategies, taking into account how environmental characteristics and contextual specificities shape their experiences. The central hypothesis is that the adoption of distinct micromobility modes is influenced not only by individual factors but also by contextual conditions, and that this adoption impacts travel strategies in diverse ways and at multiple scales, from the use of traditional transport modes to subjective experiences and spatial practices. This research is situated within a broader body of literature that explores how the introduction of new mobility actors such as micromobility can prompt behavioural changes and potentially deliver social and environmental improvements. In doing so, the thesis aims to contribute to the ongoing discussion on the potential of micromobility modes to foster a more sustainable urban transport system.

Building on these premises, a set of research questions (RQ1–RQ4) and hypotheses (H1–H4) have been formulated. This section offers only a preliminary overview of these questions, which will be examined in greater depth in Sections 4 and 5 of Part II.

A first set of considerations relates to the relationship between ownership models and modal strategies. Patterns of micromobility use may vary not only according to user characteristics but also depending on whether the vehicle is privately owned or part of a shared system. Shared systems are often thought to facilitate multimodal behaviour by offering flexibility and being more easily combined with public transport. In contrast, privately owned devices tend to foster more routinised, consistent behaviours, as users come to rely on a single mode that already satisfies their daily needs. These contrasting dynamics raise important questions about the broader implications of micromobility adoption. On the one hand, shared services may help integrate micromobility into a more sustainable and flexible urban transport ecosystem. On the other hand, the spread of private ownership could contribute to more uniform, less adaptable travel patterns. These behavioural differences also have important environmental implications: the ecological benefits of micromobility depend largely on its capacity to substitute or displace more polluting transport modes, an outcome that is less likely in dense, transit-rich urban contexts such as Barcelona. These considerations motivate the first research question and hypothesis:

**RQ1: How does the emergence of micromobility modes influence the use of traditional transport modes, and what are the behavioural and environmental implications?**

*H1: Users of shared micromobility services are expected to have more multimodal travel behaviours than users owning private devices. However, differences in modal replacement patterns may not align as clearly with ownership status.*

Beyond modal strategies and environmental outcomes, questions of equity and access are also critical concerns. The social reach of micromobility is believed to be not evenly distributed, but highly dependent on the broader mobility ecosystem in which these modes operate. On the one hand, micromobility may contribute to greater social inclusion by expanding accessibility and widening travel possibilities. On the other hand, its benefits are unlikely to be equitably distributed across all demographic groups. These considerations raise important questions about who benefits from the emergence of micromobility, and under what conditions. This leads to the second research question and hypothesis:

**RQ2: To what extent does the emergence of micromobility reproduce or challenge sociodemographic inequalities in urban mobility access?**

*H2: The emergence of micromobility is expected to benefit a broad range of users. However, the distribution of these benefits is likely to vary significantly across micromobility modes, with shared systems often offering lower potential to reduce access barriers than privately owned alternatives.*

However, understanding who benefits is not only a matter of access, it also depends on how users interact with urban space and infrastructure. Micromobility is often treat as a homogeneous entity, yet its constituent modes, such as docked bikes or private e-scooters, differ significantly in how they interact with the built environment. Just as infrastructural conditions shape the behaviour and experiences of traditional transport users in different ways, they are also expected to influence micromobility travel in mode-specific forms. These differences can lead to varied adaptations and coping strategies, which in turn affect route choices and modal consistency. These insights motivate the third research question and hypothesis:

**RQ3: How do infrastructural conditions influence travel experiences across different vehicle types, and what are the implications for travel behaviour?**

*H3: Infrastructural conditions are expected to shape micromobility travel behaviour in distinct ways across vehicle types, with variations in how* *constraints are perceived and negotiated also depending on the characteristics of the mode.*

Yet, infrastructure does more than influence behaviour, it also shapes the affective experience of movement. Infrastructure is not merely a passive backdrop for travel; it actively mediates how people feel while navigating the city. In the context of micromobility, different infrastructural configurations can elicit a wide range of affective responses, from confidence and calmness to stress or discomfort. These emotional geographies are further mediated by the physical and operational characteristics of each mode. For instance, the lightweight and manoeuvrable nature of e-scooters may generate a sense of freedom in open environments but vulnerability in traffic-heavy zones, whereas docked bikes may evoke different affective experiences tied to station location or return anxiety. These affective responses are not only relevant in themselves but are also central to understanding user satisfaction and perceived wellbeing. This line of thinking leads to the final research question and hypothesis:

**RQ4: How does infrastructure shape the affective geographies of micromobility travel, and what are the implications for users' overall satisfaction and wellbeing?**

*H4: The affective experiences and perceived wellbeing associated with micromobility use are shaped by both infrastructural conditions and vehicle-specific characteristics, with distinct emotional geographies emerging across different modes and sociodemographic profiles.*

## 1.3. Overview of the thesis

The present dissertation is a structured around a compilation of empirical studies that constitute the main core of the research project. Based on the previously presented research aims and the structure outlined in the preface, the organization of this thesis is as follows:

Part I consists of three introductory chapters. Chapter 1, already introduced, establishes the study's context and rationale. Chapter 2 presents a review of key theoretical concepts essential for understanding the applied case studies, focusing on the introduction of micromobility in urban environments and its integration within established travel behaviour theories, with particular attention to the role of sociodemographic, socioeconomic, infrastructure, and policy factors in shaping mobility choices. Following this, the general methodology and research design are presented in Chapter 3. This chapter starts by describing the multi-scale and multi-methodological approach of the thesis, followed by a contextual subsection on Barcelona and its (micro)mobility dynamics. Data sources and analyses techniques are described next, including a reflection on the use of innovative methodologies to better understand new mobility actors in urban spaces and the importance of ethics particularly when dealing with sensitive qualitative data.

The four empirical studies on which this research relies are presented in Part II. Chapter 4 encompasses two case studies, both focusing on travel behaviour at a macro-level. In a city where micromobility options face distinct regulatory frameworks, the first of the articles describes how micromobility options coexist between them and, especially, with traditional modes of transport. Following this, the analysis in the second paper narrows down and focuses into the factors influencing an individual’s choice between the two most widely used micromobility modes in Barcelona: public and docked bike-sharing system and private e-scooters. Chapter 5 shifts the analysis to a micro-level and presents two case studies that delve into how the infrastructure influences travel behaviour decisions.

Part III comprises Chapter 6, where discussion of findings from all scientific studies are merged, and Chapter 7, where some final reflections, including strengths and limitations and policy implications are provided. Finally, Part IV encompasses all the references used in this research (Chapter 8), the set of documentation provided as Annexes (Chapter 9) and a final chapter (Chapter 10), which outlines the thesis outreach and additional activities carried out throughout the PhD process. The previously presented Figure 1 visually summarizes the structure above described.

# 2. Theoretical framework

This chapter presents the theoretical foundations that inform the analytical approach adopted in this dissertation. It is structured in three parts. The first clarifies the definition and taxonomy of micromobility, outlining its evolving contours as a transport category and its disruptive potential within contemporary urban mobility systems. The second part reviews a set of conceptual traditions that offer insights into how technological irruptions can influence social practices and behavioural dynamics. Rather than committing to a single explanatory model, the thesis draws selectively from sociotechnical thinking, innovation diffusion theory, infrastructure-oriented perspectives, and social practice theory to frame behavioural change as a situated process shaped by interactions between technologies, institutions, spaces, and users. Building on these foundations, the third part identifies and unpacks four interrelated dimensions that shape micromobility-related behaviour. These include three contextual layers, namely legal and regulatory frameworks, physical infrastructure, and the surrounding transport environment, as well as one individual layer than encompasses sociodemographic attributes, personal resources, and usage motivations. This layered framework provides the basis for interpreting how micromobility practices are formed, sustained, or reconfigured in specific urban settings.

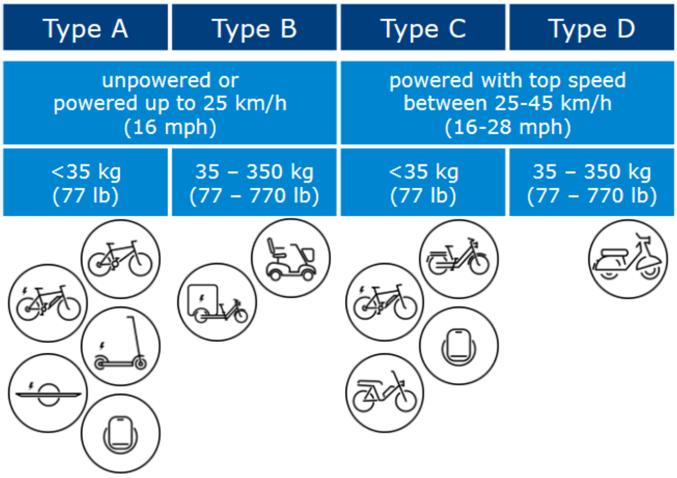
## 2.1. The irruption of micromobility: taxonomy and definition

In recent decades, the climate emergency has become one of the most pressing global challenges, with urban mobility systems playing a central role in both its causes and potential solutions. Cities and their surrounding metropolitan areas concentrate the vast majority of transport-related emissions, primarily due to high levels of private car use and the persistence of infrastructure designed around motorised mobility (Creutzig et al., 2015; IPCC, 2022) The spatial and temporal patterns of daily travel, largely shaped by land use, transport provision, and policy decisions, have led to systems that are often inefficient, socially unequal, and environmentally unsustainable (Banister, 2008). As transport remains a leading contributor to greenhouse gas emissions, transforming the way people travel within and between urban spaces has emerged as a critical priority for climate action. In this context, scholars and policymakers alike are increasingly exploring alternatives that can reduce car dependency, enhance energy efficiency, and promote more sustainable forms of transport. Some advocate for broader structural shifts, calling for compact urban forms, walkable neighbourhoods, and proximity-based planning approaches such as the 15-minute city (Ferrer-Ortiz et al., 2022; Marquet et al., 2024; Moreno et al., 2021), while others emphasise the role of digitalisation, shared mobility, or improved accessibility frameworks (Curtis & Scheurer, 2016; Papa & Ferreira, 2018). Amid these debates, micromobility has rapidly emerged as a promising development. Positioned at the intersection of individual travel choices, digital innovation, and urban governance, it introduces new possibilities for reshaping travel behaviour and reconfiguring transport systems.

Micromobility as a concept began to attract significant attention in academic and policy circles around 2019, when industry analyst Horace Dediu first coined the term (Dediu, 2019). Commonly classified under the broader category of “alternative transport modes” (Gitelman et al., 2020), the concept rapidly gained traction, giving rise to a variety of definitions and interpretations, typically referring to a wide range of lightweight, low-speed vehicles positioned between pedestrians and motorised transport modes (Bahrami & Rigal, 2021). However, as new vehicle types and services continued to emerge in diverse urban contexts, the conceptual boundaries of micromobility remain fluid, and a clear, consistent definition is still lacking nowadays. This definitional openness has allowed the term to remain adaptable, yet it has also led to confusion over what modes are included and under which conditions. In fact, this ambiguity is not merely semantic; rather, it reflects the dynamic nature of micromobility as both a technological and social phenomenon, shaped by rapidly evolving markets, urban infrastructures, and user behaviours (Pangbourne et al., 2020).

In general, classifications have typically defined micromobility based on a combination of technical parameters: mainly, vehicle weight, maximum speed, and capacity, with classifications significantly varying across countries and local jurisdictions. In an attempt to provide regulatory clarity and harmonise categorisations across member states, in 2013 the European Union (EU) approved the regulation N°168/2013, which introduced the L-category for vehicles as a reference for member countries (Regulation - 168/2013 - EN - EUR-Lex, 2013). This classification included L1e-A for 12 engine-powered cycles with a maximum speed of 25 km/h and a net power between 250 watts and 1000 watts, and L1e-B for two-wheeled mopeds up to 45 km/h and 4000 watts net power. Since this categorisation excluded human-powered vehicles, such as bicycles or scooters, several international bodies later attempted to provide definitions that encompass the diverse range of personal mobility vehicles and devices. One of those was the Society of Automotive Engineers (SAE), who modified the criteria to include vehicles or devices (1) fully or partially powered, (2) which maintained an operational weight of less than 227 kg, and (3) which had a speed of maximum 48km/h (SAE, 2019). Alternatively, the International Transport Forum (ITF) proposed a definition of micromobility as those micro-vehicles with a mass below 350 kg and a design top speed of 45 km/h (ITF, 2020). However, recognizing the challenges of establishing a universally accepted definition and highlighting the risks of grouping vehicles with markedly different kinetic energy profiles under a single category, they further proposed a four-tier classification system (Figure 2):

Figure 2. Proposed micromobility definition and classification by the International Transport Forum




Source: https://www.itf-oecd.org/safe-micromobility

In addition to the technical-oriented definitions and perspectives put forward by institutions such as the ITF, SAE, or the EU, several scholars have approached micromobility from more sociological and contextual perspectives. The interpretations of Christoforou et al. (2021) and Tuncer et al. (2020), for instance, move beyond the conventional emphasis on speed and physical specifications to introduce the notion of "hybridity". From this perspective, micromobility encompasses transport modes that allow users to shift fluidly between pedestrian and vehicular behaviours depending on situational demands, such as dismounting to cross an intersection or adopting pedestrian-like conduct in crowded or constrained environments. Other contributions, such as those by Spinney (2020) or Sheller (2020), highlight the cultural, embodied and affective dimensions of micromobility practices, emphasising how these modes are embedded within broader urban mobility systems, governance frameworks, and everyday routines. These perspectives reveal how micromobility not only introduces new transport practices but also challenges the dominant modal logic that has long structured everyday mobility, unsettling the traditional tripartite classification of transport modes - active, public, and private- by operating across and between these categories. In this line, Rérat (2021) also argued that micromobility should not be understood solely through the technical design of vehicles, but must also take into account how such modes are used, how they disrupt and reconfigure public space, and how they are shaped by social imaginaries.

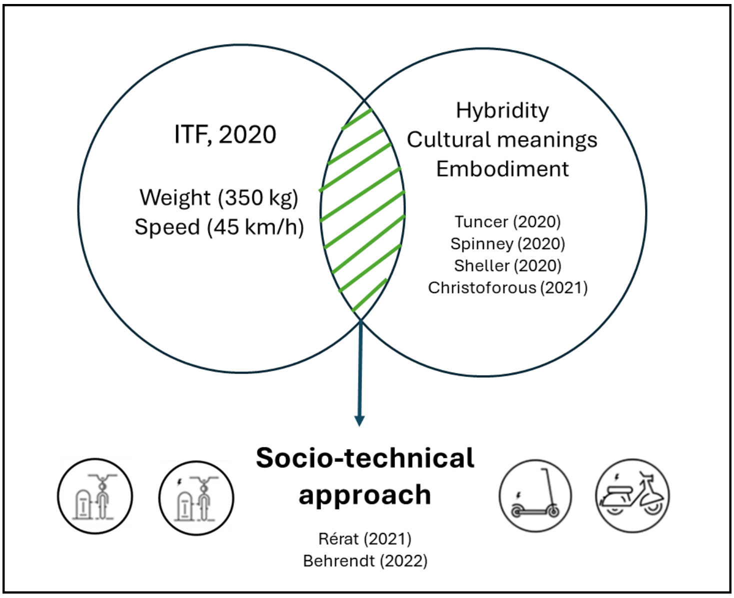
Beyond technical or sociological framings, micromobility has also been conceptualized through a more functional and operational lens, as encompassing a wide range of devices, transport modes, or services situated along a continuum ranging between private ownership to shared access (S. Bai et al., 2021; McQueen et al., 2021; Reck et al., 2021). This continuum reflects important differences not only in terms of user experience, but also in terms of infrastructure requirements, regulatory oversight, and market dynamics. While privately owned micromobility devices typically implies individual responsibility for storage, maintenance, and usage, shared systems operate through access-based models, whereby vehicles are temporarily used without ownership, often facilitated by platform-based technologies. These systems are not only reshaping user behaviours and expectations but are also introducing new governance challenges related to public space management, data regulation, and modal integration. At present, the two main types of shared micromobility services deployed internationally are station-based (also known as docked or third-generation systems) and dockless or free-floating services (referred to as fourth-generation systems) (Fishman & Allan, 2019).

On the one hand, third-generation systems, which require users to pick up and return vehicles at fixed docking stations, are usually publicly owned and municipally operated (Shaheen et al., 2020). These services often follow an annual subscription model offering unlimited or low-cost trips, and are primarily aimed at city residents (Macioszek et al., 2020). While they require substantial public funding, they promote sustainable transport and ensure affordability (Anaya-Boig et al., 2021). The predominant vehicle in third-generation systems is the shared bicycle, which is present in all major cities in the world, such as Citi Bike in New York, BIXI in Montreal, Santander Cycles in London, Vélib in Paris or Villo! in Brussels, for instance. In recent years, many of these systems have expanded their coverage areas, increased vehicle availability, and introduced electric models into their fleets. This gradual electrification responds both to evolving user preferences and to broader policy goals aimed at enhancing accessibility, extending trip distances, and further reducing environmental impact.

By contrast, fourth-generation systems allow vehicles to be parked freely in public space without fixed infrastructure. Although these are more commonly associated with e-scooters, depending on the geographical context and local mobility cultures shared e-bikes and mopeds are also frequent (Du & Cheng, 2018). Largely driven by venture capital investment, these services offer greater flexibility and can be deployed with fewer local government requirements. However, they often lead to cluttered sidewalks and conflicts over public space (Z. Chen, van Lierop, et al., 2020). Technologically, fourth-generation systems rely heavily on smartphone integration, enabling users not only to locate and unlock vehicles but also to interact with additional features such as turning the engine on or off, opening storage compartments, or retrieving a helmet. Unlike public owned schemes, these prices typically operate on a pay-per-use basis and tend to be less affordable, reflecting a shift from public service provision towards profit-oriented business models (Arias-Molinares & García-Palomares, 2020).

Building on these perspectives, this thesis adopts the definition proposed by the ITF, which describes micromobility as human- or electric-powered personal transportation (private or shared) vehicles with a speed limit no higher than 45 km/h. However, acknowledging the disruptive potential of these emergent modes within established urban transport systems (and recognising the practices, policies, cultures, and infrastructures that emerge around them and shape their uptake) this dissertation advocates for complementing that definition with nuances from some of the above-mentioned sociologically oriented approaches. In doing so, it aims to broaden prevailing vehicle-focused debates towards a more socio-technical understanding of micromobility (Behrendt et al., 2022). Based on this combined perspective, the thesis considers the following modes: docked-shared bicycles, defined as systems offering either conventional or electric bicycles for short-term rental between docking stations (Fishman et al., 2013); privately-owned e-scooters, described as standing with handlebars, a deck, and wheels, propelled by an electric motor (Shaheen & Cohen, 2019a); and moped-style scooter sharing services (hereinafter e-moped), characterised as services in which free-floating electric mopeds can be picked up and left within a geo-fenced area (Aguilera-García et al., 2020). Although privately-owned bicycles fall under most institutional definitions of micromobility, this dissertation includes only those transport options that meet a twofold criterion: first, they must challenge established modal classifications; and second, they must introduce novel spatial practices in the urban environment, thus constituting a technological irruption into existing mobility systems.

Figure 3. Conceptual delimitation of micromobility modes used in this thesis, combining technical and sociological criteria




Source: own elaboration

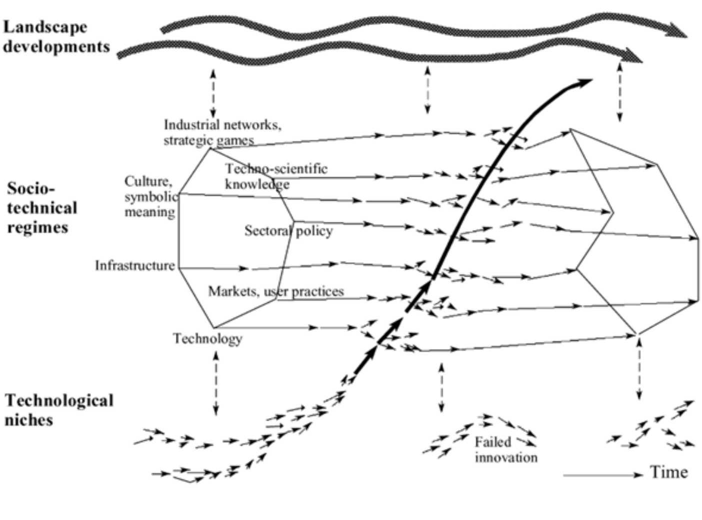
## 2.2. Theoretical frameworks on the irruption of technological innovations

Technological irruptions such as micromobility rarely enter urban systems as neutral or merely additive phenomena. Rather, they tend to unsettle established routines, disrupt spatial logics, and expose the limits of institutional and regulatory frameworks designed around older paradigms. In this sense, their impact is not confined to the material or infrastructural level; it extends to the ways in which individuals make decisions, perform routines, and navigate their everyday environments. Over the past two decades, several theoretical perspectives have sought to address this intersection between innovation/disruption and systemic transformation. While these frameworks differ in their assumptions, scales of analysis, and methodological emphases, they share a concern with how technologies interact with institutional, spatial, and cultural arrangements (and how these interactions affect what people do, how they do it, and under what conditions new behaviours emerge, consolidate, or fail to crystallise). Notably, most of these perspectives are grounded in the urban context, viewing cities as complex ecosystems where technological, social, and spatial dimensions intersect, and where the effects of innovation are most pronounced. Through this section, four of these conceptual traditions will be presented, each offering inspiring theoretical lens through which to understand micromobility as a potentially disruptive force within urban mobility systems, contributing to a situated reading of how it challenges, reshapes, or stabilises travel behaviour in contemporary cities.

### 2.2.1. Sociotechnical Transitions

A well-established conceptual tradition for analysing how technological change influences the dynamics of a system stems from sociotechnical perspectives. Rooted in Science and Technology Studies (STS), these approaches challenge the idea that innovations develop as linear, autonomous progressions. Instead, they propose that technological artefacts and social arrangements evolve in tandem, through contingent and often contested processes of alignment (Pinch & Bijker, 1984; Rip & Kemp, 1998; Shove & Walker, 2007). From this perspective, technologies are not merely tools adopted by rational individuals, but elements integrated into institutional routines, spatial configurations, and normative expectations. One influential formulation within this tradition is the multi-level perspective (MLP) developed by Geels (2002), which distinguishes between three levels of analysis: niches, regimes, and the landscape. Niches represent protected spaces where radical innovations emerge; regimes are dominant configurations that stabilise existing systems; and the landscape encompasses broader exogenous trends, such as climate change, economic crises, or pandemics, that can destabilise regimes and open windows for transition (Figure 3). As an analytical tool, the MLP has been demonstrated to be useful for identifying and engaging with diverse stakeholder groups, and has also fruitfully been applied in studies of contemporary and future transitions to sustainability, for example in electricity systems (Hofman & Elzen, 2010; Verbong & Geels, 2010), biogas and co-combustion (Raven, 2004), organic food and sustainable housing (Smith, 2007), and, more recently, urban mobility and transport systems (Bertolini, 2011; Moradi & Vagnoni, 2018; Nello-Deakin et al., 2024; Zijlstra & Avelino, 2011). Lately, authors such as Medina-Molina et al. (2022) and Behrendt et al. (2023) have even extended the framework to conceptualize and explore the challenges of integrating new mobility services into everyday practices. However, sociotechnical models have typically focused on large-scale transitions. Given the expressed and observed public resistance to changing travel behaviour, authors such as Whitmarsh (2012) defended the necessity to improve the framework by integrating behavioural and political science insights, and particularly by elucidating how behavioural–institutional change might occur.

Figure 4. A dynamic multi-level perspective on technological transitions




Source: (Geels, 2002)

### 2.2.2. Innovation Diffusion Theory

In contrast to broader system-level approaches such as the MLP, which tend to focus on structural transitions and regime-level dynamics, a second interesting perspective is the Innovation Diffusion Theory (IDT), which offers a more behaviourally grounded lens for understanding how technological changes take root. Initially developed by Rogers (1962, 2003), IDT focuses on why individuals choose to adopt or reject an innovation, emphasising that this decision is shaped not only by cost-benefit analyses but also by subjective perceptions, social influence, and communication flows. The framework identifies a series of mechanisms through which innovations are taken up by individuals and groups, including peer-to-peer influence, media exposure, and the perceived attributes of the innovation itself. Characteristics as relative advantage, compatibility with existing habits, simplicity, observability, and trialability (i.e., the potential for experimentation) are shown to significantly affect whether and how individuals decide to adopt a new practice or technology. Interestingly, rather than assuming homogenous populations, the model introduces a typology of adopters (ranging from innovators and early adopters to late majorities and laggards) each with different propensities for risk, exposure, and social conformity. This theory has been particularly influential in explaining the spread of behaviours linked to new technologies in domains such as agriculture energy, public health, and digital platforms (J. S. Brown & Duguid, 2017; Greenhalgh et al., 2017; Strang & Soule, 1998; Valente, 1996). Although the framework has been critiqued for underestimating structural and contextual constraints (MacVaugh & Schiavone, 2010), its emphasis on social dynamics, temporal rhythms, and perception-driven mechanisms makes it especially useful for analysing how new forms of behaviour gain visibility, legitimacy, and ultimately traction. More recent extensions, building on the work of Hägerstrand (1967), have incorporated spatiality into the model. In transportation-related research, for instance, scholars have examined how the spatial clustering of early adopters, urban form, and access to technology platforms can influence the pace and pattern of diffusion (Comin et al., 2012; El Zarwi et al., 2017; Zijlstra et al., 2020). These extensions enrich the original model by showing that behavioural adoption is not only shaped by communication flows or social perception, but also by geography, spatial accessibility, and territorial embeddedness.

### 2.2.3. Infrastructure Studies

A further line of research relevant to the understanding of behavioural change in the face of technological irruptions can be found in Infrastructure Studies (IS). This body of literature has highlighted how human action is deeply shaped (though often invisibly) by the physical, technological, and institutional systems that support everyday life (Edwards, 2002; Star, 1999). Infrastructures are typically taken for granted until they break down, are replaced, or come under contestation. It is in these moments of disruption or realignment that behaviours, dependencies, and practices are most clearly exposed. Star (1999) introduced the notion of "infrastructural inversion" to describe the process through which underlying systems become visible precisely when they no longer function as expected, revealing the routines, assumptions, and inequalities built into their operation. This insight has since been extended to examine how changes in infrastructure, whether gradual or abrupt, can prompt individuals and institutions to rethink practices, adjust routines, or resist transitions (Graham & Thrift, 2007a; Larkin, 2013). From this perspective, behavioural change is not driven by technology per se, but by how shifts in infrastructural arrangements reconfigure the possibilities, frictions, and affordances that condition action. Whether through the emergence of new interfaces (such as digital platforms), the reconfiguration of circulation networks (including cycle lanes or intermodal hubs, for instance), or the disappearance of previously stable systems or frames (such as the banning of devices from public transport), infrastructures play a key role in mediating how innovations are perceived, experienced, and incorporated into everyday life. Bringing to the foreground issues of materiality and contingency, infrastructure studies offer a powerful terrain to interrogate the situated, and often uneven, nature of behavioural adaptation in response to technological change or disruption.

### 2.2.4. Social Practice Theory

Finally, while the previous perspectives shed light on systemic transitions, individual adoption processes, and the infrastructural conditions of behaviour, Social Practice Theory (SPT) provides a useful framework to explore how behaviours are performed, stabilised, and transformed in everyday life. It shifts the analytical focus from actors or structures to practices themselves, seen as the interplay of materialities, meanings, and embodied competences. Practices are not static but constantly reproduced through repetition, adaptation, and interaction with the spatial and social environment (Shove, 2012). Recent extensions of this framework have incorporated insights from affective geographies, highlighting how practices are not only embodied but also emotionally charged, shaped by atmospheres, feelings, and affective responses to urban conditions (Bissell, 2010; Spinney, 2009). In mobility research, SPT has informed studies on cycling, walking, and driving, and is now increasingly applied to micromobility (Behrendt et al., 2022; Medina-Molina et al., 2022), where new practices emerge through combinations of digital interfaces, physical infrastructure, and evolving competences. Within this line of work, Fitt & Curl (2020), for instance, explored how the introduction of shared e-scooters in New Zealand cities disrupted not only transport routines but also broader spatial relations between people, places, and opportunities, highlighting the entanglement of mobility practices with social inequalities. By focusing on how behaviours are enacted and socially reproduced, SPT complements the previous frameworks by enabling a situated reading of how micromobility becomes embedded in daily life, not through linear adoption, but through the ongoing negotiation of emotional, material, and symbolic dimensions.

Table 1. Conceptual frameworks addressing technological innovation and their relevance for micromobility

| **Theoretical framework** | **Analytical focus** | **Scale of analysis** | **Key contributions to understanding micromobility** | **Micromobility dimensions addressed** |
|---|---|---|---|---|
| Sociotechnical transitions (MLP) | Interactions between technology and institutional regimes | Macro (systems, regimes, niches) | Explains structural resistance to innovation, path-dependence, and windows of opportunity | Policy environments, long-term transitions, institutional inertia |
| Innovation Diffusion Theory (IDT) | Adoption decisions based on perception and social influence | Micro/meso (individuals, adopter groups) | Highlights subjective evaluation, peer effects, and adoption rates | User profiles, communication flows, behavioural adoption patterns |
| Infrastructure studies | Role of material and institutional systems in shaping behaviour | Meso (urban networks, systems) | Reveals hidden dependencies, frictions, and affordances of infrastructure | Street-level adaptation, spatial constraints, disruptions |
| Social Practice Theory (SPT) | Routine enactment of behaviour through materials, competences, and meanings | Meso/micro (everyday practices) | Shows how practices are embodied, emotionally charged, and socially reproduced | Everyday routines, emotional responses, adaptive tactics, spatial inequalities |

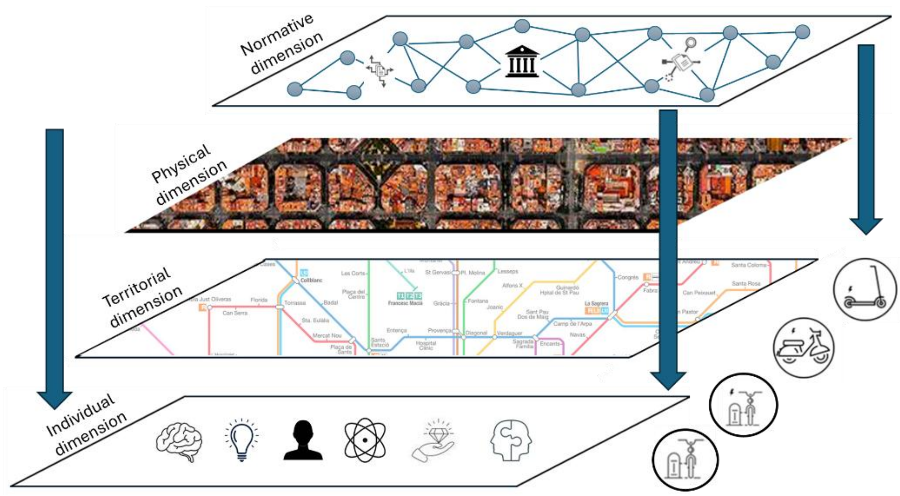
Source: own elaboration

***Error! No s'ha trobat l'origen de la referència.*** summarises the key features o f each framework and highlights the specific dimensions of micromobility that each helps to illuminate. Taken together, these theoretical traditions offer a range of perspectives on how technological innovations intersect with preexisting systems and, eventually, shape, constrain, or enable behavioural change. Whether through systemic realignments, processes of social diffusion, or shifts in infrastructural arrangements, these frameworks point to the importance of analysing behaviour as something that emerges through interaction with broader material, institutional, and cultural contexts. Therefore, rather than adhering to a single explanatory model, this thesis seeks conceptual inspiration from these traditions to inform a more flexible and layered approach. With behavioural dynamics at its core, the following section identifies four key dimensions that shape how emerging transport options are adopted, negotiated, and embedded into everyday mobility. This operational framework provides the basis for analysing micromobility-related behaviour in a way that remains sensitive to both structural constraints and personal dispositions, without losing sight of the contextual conditions under which travel decisions are made.

## 2.3. Adoption of a multilevel framework to micromobility travel behaviour

The growing presence of micromobility devices in urban areas is often framed as a promising pathway toward more sustainable, flexible, and accessible transport systems (Abduljabbar et al., 2021). Beyond its technical novelty, micromobility carries the potential to reshape how people experience, organise, and value everyday travel. Building on the insights uncovered on the previous section, this part identifies multiple dimensions that influence how micromobility becomes embedded in everyday mobility patterns. Based on existing literature, four interrelated layers have been identified as particularly influential in shaping micromobility adoption and travel behaviour: the normative dimension, the physical dimension, the territorial dimension, and the individual dimension. The first three are understood as contextual domains that structure the external environment in which mobility occurs, whereas the fourth captures the individual level, encompassing sociodemographic attributes, resources, and subjective orientations. Together, these layers provide a basis for understanding how the travel behaviour of micromobility users is shaped by their surrounding conditions and constraints (Figure 5).

Figure 5. Conceptual framework of multilevel dimensions influencing micromobility adoption and travel behaviour




Source: own elaboration

### 2.3.1. Normative dimension: regulation and institutional frameworks

Travel behaviour does not occur in a vacuum. On the contrary, the organization of urban transport systems and the behavioural dynamics they sustain are heavily shaped by public policy and regulatory frameworks. The dominance of particular transport modes cannot be interpreted as the natural or inevitable result of individual preferences, but rather as the result of historically embedded public policy decisions (Pucher, 1988). Importantly, the structuring effect of the regulatory framework is not always the result of deliberate or explicit policies, but it can also emerge through more passive processes that nonetheless shape mobility opportunities in significant ways. While the regulatory and policy framework plays a key role in shaping the rules of access and use, it also exerts a significant influence over the physical configuration of cities, over the built environment in which travel decisions take place. This becomes particularly evident in the spatial and infrastructural orientations promoted through urban planning. Decisions regarding land use, street hierarchies, and the allocation of space to different modes critically shape the accessibility, convenience, and perceived legitimacy of various travel options. As such, urban form, land use patterns, and infrastructure provision are not neutral backdrops but rather outcomes of planning choices and political priorities that, in turn, produce or result in notable differences in travel behaviour dynamics across different contexts (De Vos, 2015).

Within this frame, however, specific policies or regulations can still alter established dynamics. Such is the case of fiscal measures such as fuel taxes or emissions charges, for instance, which can change the cost of driving and encourage shifts toward alternative modes or more efficient vehicles (Klier & Linn, 2015; Meireles et al., 2021). Or policies opting for subsidies for public transit and incentives for electric vehicle adoption, including tax credits or purchase rebates, which make sustainable transportation options more financially accessible and appealing (Börjesson et al., 2020; Bureau & Glachant, 2011; Muehlegger & Rapson, 2022; Shen & Feng, 2020). In some other cases, regulatory changes have shaped modal trends with less environmentally desirable outcomes, as seen in the rise of motorcycle use in

Barcelona (Marquet & Miralles-Guasch, 2016). Regulatory interventions, such as speed limits, parking regulations, and zoning ordinances, also play a crucial role by shaping the convenience and feasibility of different transport modes (Albalate & Gragera, 2020; McAslan & Sprei, 2023).

Far from being an exception, micromobility, due to its relatively recent irruption and still-evolving definition, is particularly sensitive to policy frameworks, planning decisions, and institutional arrangements. In many cases, in fact, its rapid proliferation has forced cities to adopt reactive measures (Guéron-Gabrielle, 2023), often in the absence of a coherent long-term strategy, resulting in a fragmented regulatory landscape with rules varying significantly across (and sometimes even within) urban jurisdictions (Roig-Costa et al., 2024a). Overlapping administrative responsibilities between municipal, regional, and national authorities have further contributed to uncertainty around competencies, generating regulatory grey areas and inconsistent enforcement, particularly in relation to speed limits, sidewalk usage, or minimum age requirements (Fuller et al., 2021; Sokolowski, 2020). Licensing schemes and permitting processes have become additional points of contention, as authorities struggle to define access criteria, monitor operator compliance, and coordinate standards across jurisdictions (Bach, 2024). These institutional ambiguities have not only influenced the deployment of micromobility services and its adoption, but have also shaped how such modes are perceived, accepted, or resisted within urban governance frameworks (McCarthy, 2024). Moreover, the persistent lack of taxonomy has generated complications around insurance requirements, often leading to uncertainty and liability disputes in cases of accidents, damage, or injury (Glenn et al., 2020; Gössling, 2020).

### 2.3.2. Physical dimension: infrastructure and the built environment

The influence of the built environment on travel behaviour, comprising both natural features and human-made components, including transport infrastructure, spatial layout, and geographic characteristics, has been a central focus in transport literature. A vast body of research has demonstrated the strong association between built environment characteristics and travel behaviour, particularly through the so-called "3Ds": density, diversity, and design (Cervero & Kockelman, 1997). High-density, mixed-use, and well-connected urban areas tend to encourage non-motorised and public transport use, while low-density and car-oriented environments foster automobile dependence (Ewing & Cervero, 2010). At the same time, the provision of cycling infrastructure, pedestrian-friendly environments, or traffic-calming measures can foster conditions that support walking and cycling as viable alternatives to motorised transport (Winters et al., 2017).

In the case of micromobility, the relationship with infrastructure is particularly significant. At a broader level, the structure and layout of the urban environment are key to supporting its adoption, as the built environment must provide a sufficient concentration of destinations, along with adequate density, functional land use mix, and baseline levels of accessibility. These structural conditions define the spatial viability of micromobility as a daily travel option. At the micro-scale, research shows that micromobility users are highly sensitive to specific features of the built environment, with differences arising across different typologies of devices. E-scooter users, for instance, seem to consistently favour dedicated, one-way, and well-lit cycling infrastructure (Caspi et al., 2020; H. Yang et al., 2022; W. Zhang et al., 2021; Zuniga-Garcia et al., 2021), while showing aversion towards similar kinds of urban elements, such as sidewalks (L. Bai et al., 2017) or the presence of traffic lights (Cubells et al., 2023a; Prato et al., 2018). Docked bike-sharing users, in contrast, are strongly influenced by the spatial distribution and connectivity of the system, with usages concentrating in areas with high station density and strong integration with public transport or activity hubs.

### 2.3.3. Territorial dimension: transport availability, accessibility and culture

As above mentioned, regulatory frameworks do not merely provide a setting in which mobility practices unfold; they actively structure the field of possibilities, enabling some forms of movement while constraining or disincentivising others. For instance, sustained investment in public transportation, not only in terms of the physical expansion of rail or bus networks (Guerra et al., 2018; Mwale et al., 2022), but also through improvements in frequency, reliability, and perceived service quality (Morton et al., 2016; Redman et al., 2013), has been shown to enhance the attractiveness and practical feasibility of collective travel, often leading to increased ridership (Beaudoin et al., 2015; Padeiro et al., 2019). Over time, such interventions contribute to the consolidation of specific transport cultures: while some settings foster car-centric routines, others cultivate norms and expectations more aligned with public and active mobility. In this regard, investment in integrated transport services supports the development of multimodal systems (understood as coordinated arrangements of various transport modes) which are increasingly promoted in policy agendas as a response to the environmental and social challenges of car-dependent societies. By facilitating access to multiple transport options and encouraging their combined use, multimodal systems not only support greater flexibility in travel behaviour but also contribute to reducing car reliance, energy consumption, and emissions (Buehler & Hamre, 2016; Heinen & Mattioli, 2019). However, despite its desirability from an environmental perspective, multimodality is often perceived as burdensome at the individual level due to the inconvenience of transfers or the lack of seamless integration between modes.

In this regard, the irruption of micromobility in urban spaces has fundamentally disrupted the existing transport ecosystem. The ability to rent a shared bicycle on demand for a short period and leave it at a different location, or to alternate between public transport and an electric scooter within the same trip, introduces an unprecedented multimodal layer to urban transport systems while simultaneously reshaping the relationship between different modal options. This evolution raises a critical question in the literature: are emerging modes direct competitors to traditional ones, or do they serve to complement them? Scholars have begun to address this issue, often through the lenses of modal substitution and replacement effects (Wang et al., 2022). While the magnitude of these effects varies depending on the research context, the urban form, and the initial modal split, findings from various studies suggest a relatively consistent pattern across many cities in the Global North—namely, that a significant share of micromobility users shift from public transport. Conversely, the extent to which micromobility complements traditional modes appears to be more context-dependent, highlighting how local technological infrastructures, regulatory frameworks, and policy incentives play a key role in enabling modal integration and maximising the societal benefits of micromobility's introduction.

### 2.3.4. Individual dimension: sociodemographic profile, attitudes and motivations

Historically, travel behaviour has often been conceptualised through the lens of rational choice, particularly within transport economics, where individuals are assumed to select the alternative that offers the greatest utility, typically understood as a combination of time savings, cost reduction, and comfort.

However, this assumption has been subject to substantial critique. Scholars have pointed out that travellers do not always behave as fully rational agents, since they frequently operate under conditions of incomplete information or limited cognitive capacity, leading to what has been termed bounded rationality. In this line, Chorus & Dellaert (2012) argue that travel decisions may not necessarily aim to maximise utility, but rather to minimise anticipated regret, introducing a more psychologically plausible dimension to transport modelling. Contributions from transport geography have complemented this view by framing travel not as an isolated decision, but as a derived demand rooted in broader activity patterns. Early work on time geography (Hägerstrand, 1970) shifted attention from individual trips to travel chains and temporal constraints, a perspective that has since evolved into more holistic, life-oriented approaches to mobility (P. Zhao & Zhang, 2018). Similarly, the notion of "mobility biographies" (Lanzendorf, 2003) has highlighted how travel choices are embedded in long-term life trajectories, shaped by previous experiences and socialisation processes. Insights from social psychology have also framed travel behaviour as a reasoned action, while acknowledging the role of attitudes, intentions, and perceptions of control in shaping how individuals make transport decisions (Van Acker et al., 2010).

Taken together, these contributions highlight the relevance of the individual level in shaping mobility practices. Factors such as perceived convenience, comfort, autonomy, cost, and travel time are consistently found to influence decision-making, often mediating the relationship between objective conditions and actual choices (Anable, 2005; Mokhtarian & Salomon, 2001; Schwanen & Mokhtarian, 2005). Moreover, the perceived alignment of a mode with personal values, such as environmental concern, lifestyle, or health, has also been identified as a relevant component in shaping preferences and sustaining long-term mobility patterns (Bamberg et al., 2007; Steg, 2005). On top of that, beyond individuals' skills, preferences, attitudes, and beliefs, literature has frequently associated sociodemographic attributes such as age, gender, income level, educational background, and employment status with differences in mode choice, trip frequency, travel distance, purpose, and how people perceive and evaluate different mobility options (Kroesen, 2014a; Scheiner & Holz-Rau, 2013; Van Acker et al., 2010). Younger individuals, for instance, are often more flexible in adopting emerging modes and technologies, while older populations tend to display more stable and car-oriented habits. Gender has also been shown to influence travel patterns, with women generally demonstrating higher concern for safety and trip chaining linked to caregiving responsibilities (Crane, 2007; Nobis & Lenz, 2005). Income and car ownership, meanwhile, are commonly associated with modal access and constraints, particularly in contexts where public transport or active travel infrastructure is limited.

In the case of micromobility, although the field is relatively recent, most studies identify a common set of sociodemographic and socioeconomic patterns across different types of devices. Typically, micromobility users tend to be young, highly-educated males with full-time employment (Mckenzie, 2019; Mouratidis, 2022; Reck & Axhausen, 2021; Shaheen & Cohen, 2019a). Nevertheless, the literature also highlights important nuances across modes. Gender imbalances, for instance, appear to be more pronounced among e-scooter users (S. Bai & Jiao, 2020; Hosseinzadeh et al., 2021a; Nikiforiadis et al., 2021; Sanders et al., 2020) than among bike-sharing users (Goodman et al., 2014; Mouratidis, 2022; Roig-Costa et al., 2021). Socioeconomic indicators such as education level also yield varied findings. While most studies on bike-sharing point to a user base with higher educational attainment (Ricci, 2015; Shaheen et al., 2014), research on e-scooter use is more inconclusive, with some studies identifying a link to highly educated areas (S. Bai & Jiao, 2020;

Clewlow & Mishra, 2017; Merlin et al., 2021) and others finding no such association(Mitra & Hess, 2021a). Additionally, variables such as driver's license ownership and access to a private car are also explored, yet findings remain context-dependent and at times contradictory, both in relation to bike-sharing (Bielinski & Wazna, 2020; Eren & Uz, 2020) and e-scooter use (Blazanin et al., 2022; Mouratidis, 2022; Reck & Axhausen, 2021). These findings suggest that while certain sociodemographic patterns appear consistently across studies, the influence of individual attributes on micromobility use is also shaped by local contexts, system design, and mode-specific characteristics.

When examined through a motivational lens, several practical and perceptual factors, such as ease of use and comfort (Hardt & Bogenberger, 2019; Plazier et al., 2017; Simsekoglu & Klöckner, 2019; Teixeira et al., 2020), accessibility and flexibility (Dill & Rose, 2012; Eccarius & Lu, 2018; Esztergár-Kiss & Lopez Lizarraga, 2021; Popovich et al., 2014), or time saving (Bateman et al., 2021; Glavic et al., 2021; Kaplan et al., 2018; Krauss et al., 2022), have been found to facilitate micromobility uptake, giving these vehicles a competitive advantage over more traditional transport modes (Bretones & Marquet, 2022a). In contrast, safety concerns are consistently reported as a key deterrent, especially in environments lacking dedicated infrastructure (Fitt & Curl, 2020; Kopplin et al., 2021; Mitra & Hess, 2021a). Other functional aspects show more context-dependent effects. Monetary cost, for instance, can either hinder or encourage adoption depending on the mode and ownership model (Abouelela et al., 2021; Eccarius & Lu, 2020a; Rejali et al., 2021). Factors such as limited carrying capacity, vehicle weight, or difficulty finding available and functioning shared vehicles have also been cited as drawbacks, particularly for commuting purposes, where time and reliability are critical (Eccarius & Lu, 2020a; Sanders et al., 2020). Meanwhile, privately owned vehicles introduce other concerns, such as battery range anxiety or theft risks when parking in public space (Krauss et al., 2022; Patil & Majumdar, 2021)(. Overall, the influence of these functional factors tends to vary depending on the type of device (e.g., scooter or bicycle) and operational model (shared or private), shaping both the perceived suitability of micromobility and the frequency of its use.

# 3. Research design and methodology

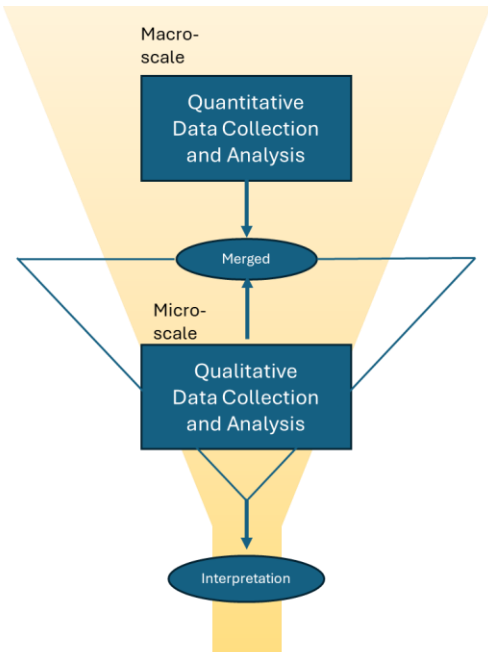
This chapter presents the different methodologies that configurate the thesis. As this is an article-based dissertation, each case study provides a detailed exposition of the selected methodologies, along with their respective justifications. Nevertheless, this introductory chapter offers a preliminary explanation of the methodological framework.

## 3.1. General research design

Framed within the scope of travel behaviour, this thesis follows a multi-scale and multi-methodological design. On the one hand, the multi-scale perspective involves a progressive shift in the scale of the analysis, moving from a broader exploration of micromobility trends (macro-scale) to a more detailed examination of micromobility interactions (micro-scale). On the other hand, multi-methodological design refers to the adoption of a mixed-method approach, specifically following a convergent design (Creswell, 2015). The thesis begins with a quantitative phase, where statistical analyses are used to identify key trends in micromobility. In contrast, the second phase employs qualitative data collection and analysis to provide deeper insights into the behavioural, spatial, and perceptual dimensions of micromobility use, particularly in relation to infrastructure interactions and travel decision-making.

By progressively narrowing the unit of analysis while integrating different methodological approaches, this thesis follows a funnel approach (Figure 6). While methodologically distinct, the two phases are treated as complementary lenses that converge during the interpretation phase, enabling the integration of broad behavioural trends with context-specific user experiences. At the macro-scale, the thesis investigates micromobility integration within the wider urban transport system, exploring how users define their mobility strategies, the complementarities between micromobility and traditional transport modes, and the factors driving micromobility adoption. This level of analysis employs quantitative methods to identify statistical relationships and capture both weekly and trip-based mobility patterns. In contrast, the micro-scale focuses on micromobility interactions with the built environment, examining how users navigate infrastructure, share space with other transport modes, and experience the embodied aspects of travel. This phase relies on qualitative methodologies, allowing for a deeper exploration of individual decision-making, spatial constraints, and user perceptions of the urban environment.

Figure 6. Multi-scale and multi-methodological research design.



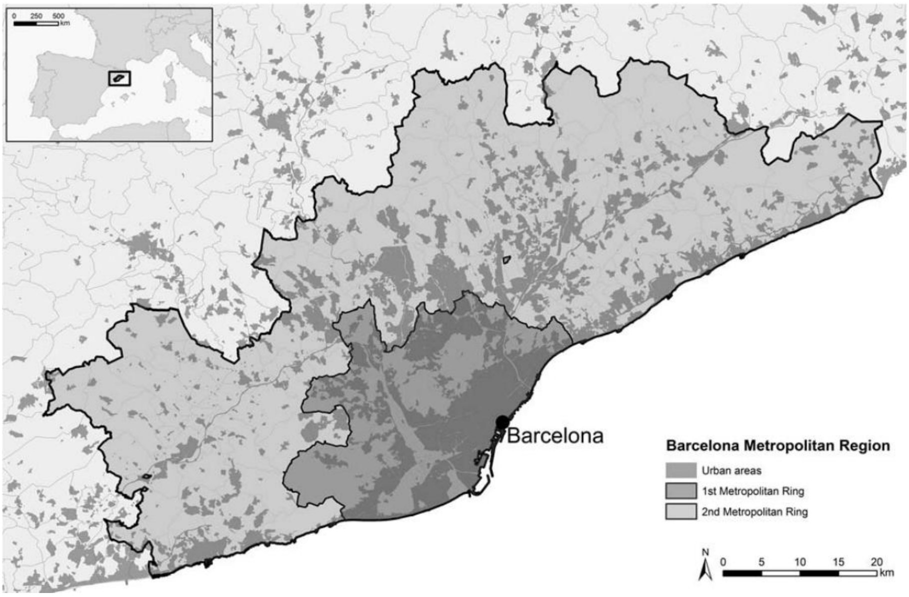

Source: own elaboration adapted from Creswell (2015)

## 3.2. Characterization of the study area

### 3.2.1. Barcelona

This dissertation explores the dynamics of micromobility modes in Barcelona, the core of the Barcelona Metropolitan Region (BMR), located in Catalonia in the northeastern Iberian Peninsula (Map 1). Positioned along the Mediterranean coast and bordered by the Collserola mountain range to the northwest, Barcelona's geographical setting significantly influences its urban development and spatial structure. Covering an area of approximately 101 $km^2$ and housing around 1.7 million inhabitants (IDESCAT, 2024), Barcelona is characterised by a dense, compact, and mixed-use urban form. This urban morphology supports a variety of land uses in close proximity, promoting short-distance travel and facilitating accessibility to services, amenities, and workplaces. While the central and coastal areas are predominantly flat (enhancing accessibility and supporting higher densities) the northern and western districts extend towards the slopes of the Collserola range, introducing steep gradients and more fragmented street networks. This topographical variation has contributed to distinct neighbourhood realities, influencing building typologies, street widths, and block sizes throughout the city.

Map 1. Location of Barcelona within the Barcelona Metropolitan Region (BMR)



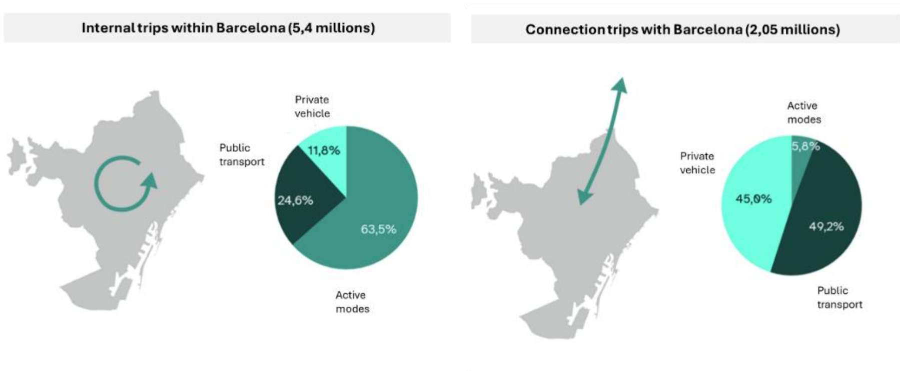

Source: own elaboration

### 3.2.2. Barcelona's mobility patterns

In contrast to cities where mobility practices are highly constrained by their spatial structure, Barcelona's urban form offers room to accommodate a substantial transition towards low-carbon mobility (Delclòs-Alió & Miralles-Guasch, 2018; Marquet & Miralles-Guasch, 2015; Nello-Deakin et al., 2024). In that sense, the city benefits from an extensive public transport network, comprising 12 metro lines, 14 train lines, and 108 bus routes, ensuring comprehensive coverage across the municipality, with connections extending beyond the city limits. While municipalities adjacent to Barcelona (particularly those integrated into the metro system), enjoy a good connection with the city, service availability gradually declines with distance from the centre. As a result, more peripheral areas experience reduced accessibility and greater reliance on private vehicles. This disparity is reflected in travel patterns, where active mobility dominates intracity trips (64%), followed by public transport

(25%), and private motorized transport (12%). In contrast, for intercity trips involving Barcelona, public transport is the predominant mode (49%), closely followed by private motorized transport (45%) and a marginal share of active mobility (6%) (Figure 7).

Figure 7. Modal share of internal and connecting trips in Barcelona.




Source: own elaboration adapted from EMEF (2023)

### 3.2.3. Barcelona's micromobility ecosystem

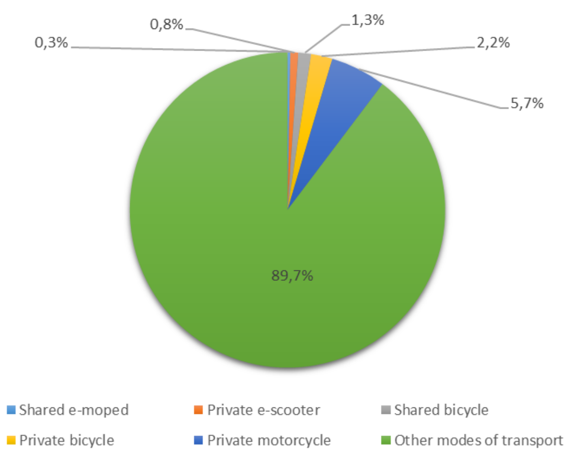
Within this context, driven by a combination of political, technical, and contextual factors, micromobility has become a prominent feature of Barcelona's urban landscape, with a wide range of lightweight vehicles increasingly visible across the city (Fluctuo, 2023). Among all of them, three alternatives especially shape Barcelona's micromobility dynamics, differing in terms of access and ownership models. In terms of shared services, the Barcelona City Council offers a well-established docked system of public bicycles under the operator known as *Bicing*. Launched in 2007, the initiative aimed to promote short-term bicycle rentals, offering non-bicycle owners an accessible option for intra-city short distance travelling. The introduction of an electrified fleet in 2019 allowed for the arrival of the system to parts of the city that were traditionally considered unsuitable for bicycle use, thus reinforcing its popularity (Soriguera & Jiménez-Meroño, 2020). By 2023, the expansion of *Bicing* had grown substantially, boasting 148,177 subscribers and achieving an average of 6.9 daily uses per bicycle (Institut Metròpolis, 2024). The system now accounts for 36.8% of all bicycle trips within the city, supported by an extensive network of 526 docked stations and a fleet of 7,608 bicycles, over half of which are electrically assisted (Bicing, 2025).

Additionally, almost ten years after the birth of *Bicing*, between 2016 and 2017, the first shared e-moped services were launched in the city. Initially, a few venture capital firms landed without following any specific regulations, which translated into companies offering the service according to profitability criteria and concentrating the supply in the central area of the city. In 2019, after a few months of dialogue between the Barcelona City Council and the operators, the operation of shared motorbikes started a process of regulation (Ajuntament de Barcelona, 2019). The purpose was to set the number and regulate the conditions for granting temporary licenses for special common use of the public domain. Initially, the number of licenses was set at 6,958, subjected to annual revisions. In May 2020, the licenses were definitively awarded, and during the summer of 2020 moped-style sharing companies started to operate within the city limits. Currently, the number of companies providing such services has reduced to nine, and the number of licenses to 5,407. Although accounting for only 5.6% of total trips made on two-wheeled motor vehicles in the city, shared e-mopeds have become an integral component of Barcelona's micromobility ecosystem.

On the other hand, in contrast to the more permissive attitude during the drafting of the regulatory framework and licensing process of moped sharing services, the Barcelona City Council adopted a restrictive stance towards free-floating e-scooter companies, such as Lime and Bird, prohibiting them from operating within the administrative boundaries of the city since 2017

(Ajuntament de Barcelona, 2017). This decision was mainly aimed at avoiding problems related to parking malpractices and the occupation of public space, problems that had been observed in other cities where shared e-scooter systems had been implemented. A direct consequence of these prohibitions was an increasingly popular boom in privately owned e-scooters use, showing increments of about 169.2% from 2017 to 2018 (EMEF, 2018), and reflecting a shift towards individual ownership in the absence of shared alternatives. Other contextual factors, such as the COVID-19 pandemic, later consolidated and accelerated their deployment (Nello-Deakin et al., 2024), as they were perceived as safer alternatives to public transport modes (A. Li et al., 2021). In October 2023, partially reinforced by the restrictive decision taken in Paris (Bach, 2024), Barcelona City Council definitely ruled out any regulatory framework for shared e-scooters, positioning itself among a group of major European cities that have opted against allowing shared e-scooter schemes, such as Luxembourg, Amsterdam, and Geneva. Nowadays, e-scooter trips account for 0,8% of daily trips in Barcelona, keeping a constant and steady growth since their boom (EMEF, 2023).

Figure 8. Modal share of the 3 main micromobility modes in Barcelona.




Source: own elaboration with data from EMEF (2023)

## 3.3. Data sources

At the time this thesis was initiated, official mobility surveys did not provide disaggregated data on micromobility modes. This thesis therefore draws on data collected within the framework of the project *New Mobility in the City* (NEWMOB) (Roig-Costa et al., 2021), which was specifically designed to explore the travel behaviour and lived experiences of micromobility users in Barcelona. To this end, two complementary sources of data were employed: an ad-hoc travel survey, which provides quantitative information on travel behaviours and was aimed at identifying behavioural patterns and user profiles, and a series of interviews, which provide qualitative information on mobile experiences and focused on how users experience and navigate the urban environment.

### 3.3.1. Micromobility survey

The first source of information analysed was the *Enquesta de Perfils i Usos de Vehicles de Micromobilitat a Barcelona* (EPUVMB; Survey of Profiles and Uses of Micromobility Vehicles in Barcelona, in English). The survey was administrated between September 15th and October 1st, 2020, with data collection carried out by eight trained pollsters strategically positioned across various locations throughout the city of Barcelona (Map 2). Fieldwork took place on weekdays days between 9 a.m. and 8 p.m., employing a Computer-Assisted Personal Interviewing (CAPI) technique. Participants were randomly intercepted on the street and at bike-sharing stations before, during or after completing a micromobility trip and were invited to participate in a structured questionnaire, which typically lasted 10 to 15 minutes.

The questionnaire covered multiple aspects of micromobility use and travel behaviour, including questions on current and past mobility patterns, exploring preferences, motivations, and the frequency of use of both micromobility modes and traditional transport options. Additionally, it investigated the reasons for choosing micromobility, the satisfaction levels, and the extent to which these modes were substituting other forms of transportation. To contextualise these findings, the survey also collected socio-demographic information on respondents. Eligibility criteria required participants to be at least 16 years old (the minimum age for operating an e-scooter or using the public docked bike-sharing system) and to either live or work in Barcelona. The final sample comprised 902 micromobility users.

Map 2. Geographic distribution of survey interception points and catchment area for the EPUVMB

Source: own elaboration

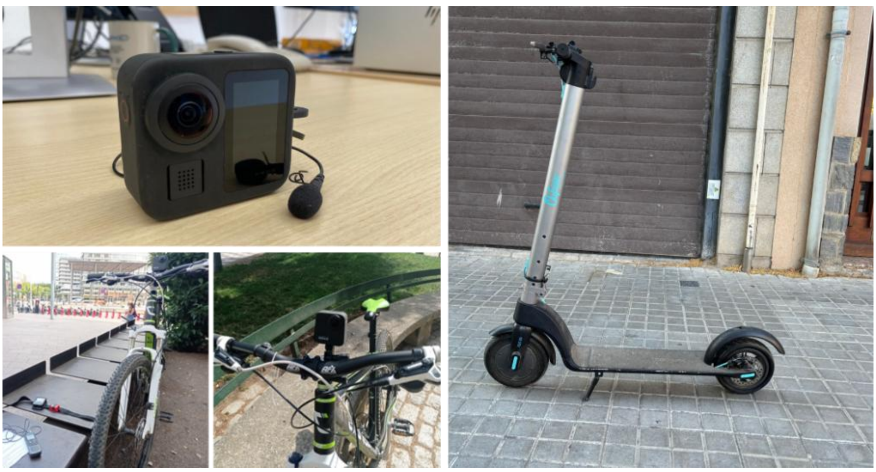
### 3.3.2. Interviews

Additionally, to deepen the insights gained from the first stage of data collection, the study incorporated a qualitative phase aimed at examining how the introduction of micromobility integrates into a preexisting urban ecosystem. Rather than focusing solely on general travel strategies, this phase explored how micromobility users interact with both the built environment and other urban actors, identifying the challenges that emerge from this coexistence and the ways in which users navigate shared urban spaces. To that end, the EPUVMB served as a recruitment tool for this stage, with participants invited at the end of the questionnaire to take part in a follow-up study. Those who expressed interest were recontacted months later to participate in in-depth interviews. This second data collection stage finally took place during June and July 2022 and involved a dual approach: a mobile interview conducted during real micromobility trips (i.e., ride-along), and a subsequent static interview performed immediately after the trip.

Ride-along were chosen to capture the embodied experiences of micromobility traveling and to explore micromobility nuances at a street level. Prior to the ride, participants completed a short survey that collected basic background information (age, gender, years of e-scooter use) alongside evaluative questions about the forthcoming trip, including the Satisfaction with Travel Scale (STS) (Ettema et al., 2011). Administering the STS at this early stage allowed to capture participants' anticipatory evaluations of the trip, while also providing participants with a more nuanced emotional vocabulary capable of triggering precise reflections during the ride-along itself (Bissell, 2010; Hein et al., 2008). The interviews were tape-recorded, GPS-tracked, and video-documented using a GoProMax camera installed on the researcher's handlebar, offering a unique opportunity to explore micromobility routes, spatial interactions, and user experiences, enabling discussions that might not otherwise arise (Wegerif, 2019). Participants were instructed to select a routine trip that they perform on a regular basis and, recognizing the challenges of maintaining a coherent conversation while riding a micromobility vehicle, they were advised against trying to engage in dialogue with the researcher. Instead, before starting the ride the main researcher read out a text with basic instructions encouraging them to share their reflections in a think-aloud monologue format, without expecting a response from the researcher. To ensure continuity and immersion during the ride-alongs, the researcher mirrored the participant's vehicle alternative (cycling alongside users of shared bicycles and using an e-scooter when accompanying e-scooter riders).

At the end of the ride-along, the video camera was turned off, and the static and semi-structured interview based on the previous trip took place with each participant. This lasted approximately 30 minutes and involved a discussion of the attitudes, decisions and behaviours engaged by participants during the recorded trip, as well as their past e-scooter experience, information which provided important context. During this phase of the study 29 participants were interviewed, which translated into a total of twelve hours of video and almost twenty-three hours of interviews.

Figure 9. Fieldwork equipment and devices for mobile interview data collection



Source: author's own

### 3.4. Analyses techniques

#### 3.4.1. Quantitative techniques

The quantitative component of this research, comprising two case studies, draws on data from the EPUVMB survey, offering insights into micromobility trends and user preferences from a macro and broad travel behaviour perspective. On the one hand, the first case study, based on a sample of 902 micromobility users (326 private e-scooter users, 325 bike-sharing users, and 251 moped scooter users), relies on weekly-level data and follows a three-step approach. First, cluster analyses were applied to identify homogeneous groups of micromobility users. Second, bivariate correlations were conducted to examine the relationship between the identified clusters and the usage frequency of traditional transport modes. Finally, a multinomial logistic regression model was performed to estimate the key factors associated with each group of travellers.

On the other hand, the second case study focused exclusively on micromobility modes operating within the same dedicated urban infrastructure, specifically private e-scooters (326) and shared bicycles (325). Drawing on trip-level data, a four-step analytical approach was adopted to (1) characterise the user profiles of the two most widely used micromobility alternatives in Barcelona; (2) identify the key socioeconomic and mobility-related factors influencing the choice of private e-scooters over the bike-sharing system; (3) examine the origins of demand for each micromobility mode; and (4) assess users' subjective evaluations of their respective micromobility experiences. Quantitative analyses were performed running the klaR package of the R statistical computing environment and the NOMREG procedure in IBM SPSS Statistics version 21.

### 3.4.2. Qualitative techniques

The second level of the methodological design of this dissertation is based on qualitative techniques. Specifically, the third and fourth case studies are based on the materials extracted from the abovementioned 29 individual in-depth interviews with bike-sharing users and private e-scooter users. The aim of this qualitative work was to understand the experience of the everyday practice of using a micromobility device within Barcelona's urban fabric, how this was influenced by the existing infrastructure and how it was emotionally managed by participants.

The analysis consisted of two stages. The first stage involved the observation of the videotaped trips. Video recordings of the mobile interviews were downloaded to the researcher's laptop on the same day the interviews took place, and users' behaviours were then audited and categorized with the aim of identifying common and discordant patterns in terms of navigating the city. This behavioural and spatial interaction phase was supported by Atlas.ti® software, which facilitated the organisation, tagging and systematic management of large volumes of qualitative data. Complete behavioural indicators, such as speed changes, manoeuvring tactics, and adaptation to environmental cues were audited to capture recurring actions or anomalies (see Table 2 as example).

Table 2. Example of e-scooter participants behavioural riding audition

| | Participant Code | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | ESC01 | ESC02 | ESC03 | ESC04 | ESC05 | ESC06 | ESC07 | ESC08 | ESC09 | ESC10 | ESC11 | ESC12 |
| **Trip details** | | | | | | | | | | | | |
| Length (in km) | 1,5 | 2,6 | 6,7 | 2,6 | 5,4 | 3,8 | 4,2 | 3,9 | 4,5 | 3,6 | 1,9 | 2,6 |
| Door to door (in minutes) | 10 | 5 | 32 | 12 | 24 | 20 | 28 | 27 | 19 | 20 | 11 | 11 |
| Riding time (in minutes) | 6 | 5 | 26 | 11 | 24 | 19 | 12 | 25 | 19 | 19 | 10 | 11 |
| Walking time (in minutes) | 4 | 0 | 6 | 1 | 0 | 1 | 16 | 2 | 0 | 1 | 1 | 0 |
| Average speed (km/h) | 9,9 | 12,1 | 9,4 | 8,6 | 14,8 | 8,5 | 8,1 | 10,5 | 11,2 | 9,3 | 7,5 | 12,6 |
| Maximum speed (km/h) | 25,0 | 22,2 | 31,8 | 24,4 | 30,5 | 26,5 | 28,1 | 20,9 | 27,4 | 25,1 | 20,2 | 27,1 |
| **Space location** | | | | | | | | | | | | |
| One-way bike lane | Right | n.d | Right | Centred | Centred | Right | Right | Left | n.d. | Right | Centred | n.d. |
| Two-way bike lane | Centred | n.d | Centred | Centred | Centred | Centred | Right | Right | Right | Centred | Right | Centred |
| Bicycle sharrow (10 or 30 km/h) | Right | Centred | Centred | n.d. | Centred | Right | Right | Centred | n.d. | Centred | Right | Centred |
| **Actions** | | | | | | | | | | | | |
| Committed overtaking | 0 | 0 | 7 | 1 | 6 | 5 | 2 | 4 | 1 | 3 | 0 | 4 |
| Received overtaking | 1 | 0 | 6 | 0 | 0 | 3 | 5 | 1 | 3 | 1 | 6 | 1 |
| Yielding to a pedestrian when mandatory | 1 | n.d. | 1 | 0 | 1 | 3 | 1 | 1 | 2 | 1 | 2 | 1 |
| Not yielding to a pedestrian when mandatory | 0 | n.d. | 1 | 2 | 1 | 0 | 0 | 0 | 0 | 2 | 0 | 1 |
| Changing status | 1 | 0 | 3 | 1 | 0 | 3 | 4 | 1 | 0 | 1 | 1 | 0 |
| Crowding at front line in traffic light | 0 | 0 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Waiting between red light and junction | 0 | 1 | 0 | 3 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 0 |

Source: own elaboration

The second stage involved a thematic analysis of the participants' discourses, combining insights from the trips themselves with those generated during subsequent static interviews. All the audio recordings were transcribed, and the thematic analysis was conducted systematically, with codes and themes generated inductively from the data and guided by the research objectives. In this process, transcripts were coded based on the emergent concepts identified in each excerpt. These initial codes were later refined and grouped into broader categories, which served to structure the thematic blocks. Following the approach outlined by Sandelowski (2001), qualitative data was then integrated with quantitative counts of participants who discussed specific environmental factors to support the description of our findings, 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%.

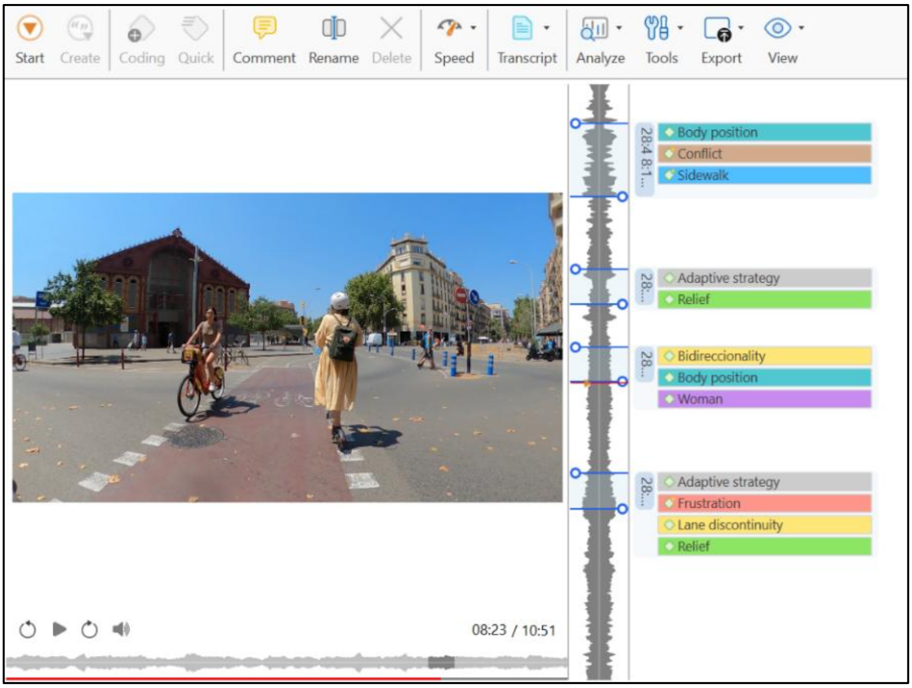
Table 3. Example of quotations and coding within the thematic analysis stage

| Interview | Mode | ID | Quote | Codes |
|---|---|---|---|---|
| 1 | Bike-sharing | BSS01 | "Yesterday I took an electric whose brakes didn't work well. With your bike you know exactly how to brake, you control everything. With *Bicing* each bike is a world. You always have that moment where you have to raise and lower the seat [...] and if the brakes don't work well, it's a bit awkward." | Mechanical issues; Uncertainty |
| 7 | E-scooter | ESC02 | "The type of bike lane that makes me feel most comfortable is the one that is segregated, clearly. Either unidirectional or bidirectional but segregated." | Segregation; Comfort |
| 8 | Bike-sharing | BSS06 | "[...] Riding with the cars is hard because they go very fast and complain a lot." | Speed differential; Unsafety |
| 11 | E-scooter | ESC05 | "Man! If there were real cycle lanes... But you see there aren't any. And on top of that, everything is disconnected." | Lane discontinuity; Frustration |
| 13 | Bike-sharing | BSS08 | "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." | Width; Safety |
| 18 | Bike-sharing | BSS12 | "Well, it all depends on the speed of the others. In the end, the point of sharing space and feeling safe is to have similar speeds." | Speed differential; Unsafety |
| 19 | E-scooter | ESC07 | "Yes, to save time and because if you wait until it's your turn, those coming along Gran Vía are already on their way. It is poorly designed." | Infrastructure shortcoming; Adaptive strategy |
| 24 | E-scooter | ESC09 | "Yes, I'm like that. I always lose out to avoid fuss. You always meet cocky people...I've also seen some fights when people were invading a lane and the person in front of me said something to them and they started arguing... E-scooters and bikes alike. And I don't feel like it. I prefer to stay out of the way and be calm." | Conflict; Body position; Woman |

Source: own elaboration

Finally, to ensure the validity of the data, video recordings were systematically reviewed alongside the interview transcripts in order to capture contextual and non-verbal cues, allowing for a more comprehensive understanding of participants' experiences. These recordings, produced for each interviewee and structured around thematic focus, were analysed in conjunction to address the research questions guiding the third and fourth case studies. Combining video and audio data enabled the precise synchronisation of what participants said with when and where they said it during the ride-along. This temporal alignment made it possible to interpret verbal expressions in direct relation to the spatial and infrastructural conditions that triggered them. Situational reactions, such as shifts in tone, emotional outbursts, or moments of reflection, were therefore not treated as isolated statements, but as embedded responses shaped by the ongoing experience of navigating the city. This dynamic reading of the data enriched the thematic analysis by anchoring meaning in the real-time circumstances of travel Both the transcript review and the coding process were supported by Atlas.ti® software, which facilitated the organisation, tagging, and systematic management of large volumes of qualitative material (Figure 10).

Figure 10. Visual representation of the integration of discourse, visual, and spatial layers in Atlas.ti®




Source: own elaboration

### 3.4.3. Research ethics

The NEWMOB project was formally registered with the Research Ethics Committee (Comitè d'Ètica en Recerca, CERec) of the Universitat Autònoma de Barcelona under reference number 3656. The study adhered to ethical research guidelines, ensuring that all procedures related to participant recruitment, informed consent, data collection, and data management complied with established ethical standards. Both the survey and interview protocols, as well as the procedures governing consent and the handling of personal data, received approval from CERec, guaranteeing that participants' rights, privacy, and confidentiality were safeguarded throughout the research process.

Table 4. Summary of the case studies in the thesis, their aims, their relationship to the research questions and the methodology used

| Case study | Study aim | Sample | Research Questions | | | | Methodology | Data sources | Analytical approach |
|---|---|---|---|---|---|---|---|---|---|
| | | | RQ1 | RQ2 | RQ3 | RQ4 | | | |
| Case Study 1 | User profiles and travel behaviour strategies among micromobility users | 902 | ■ | ■ | | | Quantitative | Ad-hoc micromobility survey (EPUVMB) | Cluster analysis + multinomial logistic regression to identify weekly travel strategies and profiles |
| Case Study 2 | Micromobility adoption choices in a fragmented regulatory ecosystem | 651 | ■ | ■ | | ■ | Quantitative | Ad-hoc micromobility survey (EPUVMB) | Descriptive statistics + binomial logistic regression to identify predictors of micromobility adoption |
| Case Study 3 | Experiential dimensions of docked bike-sharing in Barcelona | 17 | | ■ | ■ | ■ | Qualitative | Video recorded mobile interviews + Post-ride static interview | Thematic analysis + situational interpretation based on synchronized video–verbal data |
| Case Study 4 | Affective geographies of private e-scooter use and adaptive behaviours | 12 | | ■ | ■ | ■ | Qualitative | Video recorded mobile interviews + Post-ride static interview | Thematic analysis + situational interpretation based on synchronised video–verbal data + affective mapping responses to infrastructural constraints |

Source: own elaboration

# PART II - FINDINGS

# 4. Micromobility at a systemic level: trends, profiles and strategies

## 4.1. Understanding multimodal mobility patterns of micromobility users in urban environments: insights from Barcelona

Transportation
https://doi.org/10.1007/s11116-024-10531-3

### Understanding multimodal mobility patterns of micromobility users in urban environments: insights from Barcelona

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**Abstract**
Micromobility, which includes bicycle-sharing systems, e-scooters, and shared moped-style scooters, has emerged as a popular alternative to traditional transport modes in urban environments, thus expanding the number of transportation options available to urban travellers. Previous research has primarily relied on trip-based data to explore the multimodal character of micromobility. However, existing evidence has failed to understand the ways in which urban travellers have reshaped their mobility patterns as a consequence of the introduction of micromobility. Using a travel survey (N = 902) set in Barcelona, Spain, cluster techniques are used to group micromobility users according to their frequency of use of three different micromobility modes (bicycle-sharing systems, private e-scooter, and moped-style scooter-sharing services). Then, a multinomial logistic regression was used, in order to explore each cluster's usage of traditional modes of transport, along with all potential weekly combinations between modes. Results show that most micromobility users rely on a single type of micromobility mode on a weekly basis. The model further indicates that private e-scooter, shared bicycle, and shared moped-style scooter users develop different weekly mobility combination patterns. While personal micromobility options (private e-scooter) are associated with monomodal tendencies, sharing services (bicycle sharing and moped-style scooter sharing) encourage multimodal behaviours. These findings contribute to the limited knowledge concerning the role of some micromobility alternatives in creating more rational and less habit-dependent travel behaviour choices.

**Keywords** Micromobility · Bicycle-sharing system · E-scooter · Moped-style scooter sharing · Travel behaviour · Multimodality

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JCR (2023): Impact Factor (IF) = 3,5, Journal Rank = **Q1** (Civil Engineering); **Q2** (Transportation).

### 4.1.1. Introduction

From environmental, sociological, and economic perspectives, micromobility has the potential to promote a sustainable urban future (Hosseinzadeh et al., 2021a). One frequently cited argument is that the rise of micromobility can contribute to the reduction of car use and its associated negative impacts, such as emissions, noise, and congestion (Wang et al., 2022), while also promoting the use of public transport, which includes buses, trams, trains, and the metropolitan underground railway system (hereinafter, metro) (Hosseinzadeh et al., 2021c; Oeschger et al., 2020). While the exact extent of the tangible benefits of micromobility is still under debate (S. Sun & Ertz, 2022), its deployment in urban settlements has been gradually expanding, thus adding variety and complexity to urban transportation systems (Alessandretti et al., 2022). However, without a clear understanding of the ways in which these modes are being used, it is challenging to test most assumptions on micromobility's potential benefits, and then verify them. Hence, gaining insight into the role of micromobility in people's travel behaviour has become more important than ever. This paper contributes to the discussion about the multimodal or unimodal nature of micromobility in urban transportation, with a particular emphasis on understanding the usage patterns of micromobility. It examines whether micromobility users tend to exclusively rely on a single mode of transportation for all their travel needs or they incorporate micromobility options as complementary to traditional transportation modes. This understanding is crucial for planning and policies aimed at promoting cycling and multimodal transport.

Micromobility is a broad concept with no consensus definition (Oeschger et al., 2020). In the context of shared mobility, for instance, some definitions include only modes that enable individuals to conveniently switch between pedestrian and personal mobility vehicles (PMVs). Common examples include shared bikes or shared e-scooters, both designed for a single passenger and typically not exceeding speeds of 25 km/h (Shaheen & Cohen, 2019b). However, given the rising popularity and significance of other mobility options in urban settings, this paper adopts the broader definition provided by the International Transport Forum, (2020), which describes micromobility as human or electric-powered personal transportation (private or shared) vehicles with a speed limit no higher than 45 km/h. On this basis, the following micromobility transport modes are taken into consideration for the purpose of this paper: docked-shared bicycles, understood as *those systems that offer either conventional or electric bicycles to enable short-term rental from one docking station to another* (Fishman et al., 2013); privately-owned e-scooters, identified as *scooters with a standing design with a handlebar, deck and wheels that are propelled by an electric motor* (Shaheen & Cohen, 2019a); and moped-style scooter sharing services (hereinafter e-moped), characterised as *those services in which free-floating electric mopeds can be picked up and left within a geo-fenced area* (Aguilera-García et al., 2020). Although some studies consider private bicycle as a micromobility option, this paper focuses on transportation choices that have recently emerged in cities (Shaheen & Cohen, 2019a).

Micromobility and its integration into multimodal transportation systems has been a topic of interest in recent years. Traditionally, travel behaviour has been recognised as being significantly influenced by the impact of human habits (De Witte et al., 2013). However, the advent of micromobility might be challenging this assumption. Having a bike-sharing option available, for instance, could give people more confidence in their travel options, allowing them to rely less on privately owned vehicles (POVs) for unexpected trips during the day. Similarly, being able to bring personal e-scooters on the underground (railway/metro) for first/last mile trips could increase satisfaction with public transport and potentially draw drivers away from cars. This flexibility might enable people make more rational and adaptable transportation choices based on trip-specific needs. Therefore, understanding the capability of micromobility in shaping user's preferences and attitudes towards the whole transportation supply is crucial in calibrating its impact, and for designing smarter and equitable transport management policies. To date, most of the research has mainly focussed on micromobility as a part of a trip chain, either in the context of access and egress trips to and from public transport (integration effect) (Bordagaray et al., 2016; Reck et al., 2022; Wong et al., 2020), or in counterfactual scenarios prior to micromobility trip realisation (substitution effect) (Reck et al., 2022; Ricci, 2015; Wang et al., 2022). However, since humans tend to develop or adhere to a set of patterns in their daily lives (Nobis, 2007), there is a need to complement these approaches and to take a broader perspective by observing micromobility on a weekly basis. Understanding the weekly patterns of micromobility use can help comprehend its role in multimodal transportation systems, and its contribution to overall travel behaviour. This research topic is particularly important when the issue under debate is micromobility's potential to influence the development of individual daily transport patterns.

Based on the above-mentioned issues, this paper seeks to answer the following research questions (RQ): (1) *What are the different profiles of micromobility users,* and (2) *Which factors influence their adoption of multimodal travel patterns?* To address these questions, this study proposes the following hypotheses to be tested:

Hypothesis 1 (H1): An overlap is expected in the usage of shared micromobility systems (i.e., bicycle-sharing and moped-style scooter sharing), while not between shared systems and privately-owned devices (i.e., private e-scooters).

This hypothesis is based on the premise that shared micromobility options are thought to act as a gateway to other shared micromobility options, encouraging users to explore and utilize multiple shared services (Aguilera-García et al., 2020; Liao & Correia, 2022). In contrast, owning a micromobility device might be discouraging users to integrate extra shared services in their mobility patterns, as their micromobility needs might be already covered by the owned device itself.

Hypothesis 2 (H2): Shared micromobility users are expected to integrate traditional transport modes more intensively in their weekly travel patterns compared to users with a privately owned micromobility device.

This second hypothesis stems from the understanding that shared micromobility systems are thought to complement and extend existing traditional travel options (Wang et al., 2022). Users of sharing services most likely will show multimodal travel behaviour (i.e., not always choosing the same mode for each trip). In contrast, private micromobility vehicle ownership may lead to an abuse or an indiscriminate use of the mode of transport in question, i.e., a tendency to always use the same vehicle for different reasons or necessities, pattern observed for other privately-owned vehicles (Garcia-Sierra et al., 2018).

This study uses data from a travel survey conducted in Barcelona, Spain, and is based on a three-step analysis. First, in order to identify homogeneous groups of micromobility users (1) a clustering analysis based on the weekly frequency of use of the three different micromobility options was performed. This first step addresses RQ1 by revealing different profiles of micromobility users. The clustering analysis helps test H1 by determining whether there is overlap in the usage patterns of distinct micromobility alternatives. Second, in order to identify which of these cluster groups are more likely to develop multimodal travel behaviours (2) a bivariate analysis was conducted. This step addresses RQ2 by exploring the relationship between cluster membership and multimodal travel patterns and helps test H2 by identifying whether users of shared systems exhibit more multimodal mobility patterns compared to users of private devices. Finally, in order to estimate who was more likely to belong to each cluster (3) a multivariate analysis was performed based on the frequency of use of traditional transport modes and sociodemographic attributes. This step further addresses RQ2 by determining the factors influencing the adoption of multimodal travel patterns. The multinomial logistic regression model helped test both H1 and H2 by quantifying the likelihood of cluster membership in relation to various predictors.

The remainder of the paper is structured as follows. Section 2 reviews how multimodality has been previously approached, as well as their link(s) with micromobility. Section 3 presents the study area, the data collection process, and a description of the methodology used. Section 4 provides the main results, while Section 5 discusses those results, including a reflection on the role of micromobility in making cities and the transport system more sustainable and resilient. Finally, some conclusions and study limitations can be found in Section 6.

### 4.1.2. Literature review

#### 4.1.2.1. Multimodality

Multimodal travel behaviour, defined as the utilisation of two or more modes of transportation within a specified interval of time (Diana & Pirra, 2016), has garnered attention from researchers within the mobility and transportation field during the last two decades. Studies have found that the composition and existence of multimodal patterns is largely contingent upon the definition and measurement of the period of time under study. A particular instance of multimodality, for example, is intermodality, which involves the use of two or more transportation modes within the frame of a single trip, highlighting the consecutive integration of different transportation options to achieve a single purpose (Gebhardt et al., 2016). Beyond individual trips, multimodality has also been explored considering broader patterns of transportation use over extended periods. Particularly, as standard temporal unit that aligns with regular societal and cultural rhythms (Nobis, 2007), the week has proven crucial for understanding the cyclical nature of travel behaviour, as evidenced by its widespread use across different authors and contexts (Garcia-Sierra et al., 2018; Heinen & Mattioli, 2019; Kuhnimhof et al., 2012). Focusing on weekly patterns has enabled researchers to capture the regular, repeatable aspects of mobility that reflect both habitual behaviour and structured weekly activities, which has provided insights into how people plan and coordinate their use of various transport modes to meet their weekly schedules and commitments. Furthermore, some other research have even extended the time span by examining multimodal behaviours on a monthly (Lee et al., 2020; Miramontes et al., 2017) and annual basis (Alessandretti et al., 2022; Fu et al., 2024), providing a broader perspective on transportation patterns.

The importance of defining the temporal aspect of multimodality was first emphasised by Buehler & Hamre (2016), who showed that longer timeframes captured a greater degree of variability in travel behaviour. Based on data from the US National Travel Survey, they revealed that although American motorists typically relied on automobiles for roughly 93% of their daily trips, 25.1% of them used another mode of transportation for at least seven trips per week, and 13.5% regularly walked, cycled, or utilised public transportation for at least two trips per day. Following a related approach, Nobis (2007) used the 2002 German Mobility Survey to study multimodality patterns in Germany.

The author found that 49% of the German population used more than one of the three modes of transportation (car, public transport, and bicycle) at least once per week. Similarly, Kuhnimhof et al. (2006) used multiday data from the German Mobility Panel (MOP) to analyse individual mode choice behaviour in Germany. Their findings showed that about half of German drivers also used public transport. Moreover, besides the diversity of transport mode use, authors typically include detailed intensity or evenness measures to refine their definitions of monomodality and multimodality. Vij et al. (2011), for example, defined individuals using the same transport mode for over 90% of their trips as individuals with monomodal tendencies. Other authors applied a scale ranging from 0 to 1 (where values closer to zero indicated a multimodal travel behaviour, and values near to 1 suggested a monomodal travel behaviour), confirming great degrees of variability in day-to-day travel behaviour (Heinen & Chatterjee, 2015). More recently, in an attempt to address the mode classification issue in measuring multimodality, Fu et al. (2023) constructed a multigroup multimodality index to measure the extent of the variability of transport mode use, effectively distinguishing the degrees of multimodality across different modes and groups.

#### 4.1.2.2. Multimodality and micromobility

The introduction of micromobility in cities has substantially expanded the number of transportation options available to urban travellers. Modestly accelerated by the COVID-19 pandemic and consolidated in its aftermaths (Azimi et al., 2024; Bustamante et al., 2022; Nello-Deakin et al., 2024; Rossetti et al., 2024), micromobility popularization has added new travel opportunities, increasing the multimodality potential of urban transportation systems and allowing travellers to combine different modes of transportation to create more efficient and personalised travel experiences. This is expected to result in reduced congestion, lower emissions, and improved access to different parts of the city, ultimately contributing to a more sustainable and liveable urban environment. Given these potential benefits and the important influence on urban transportation and mobility patterns, researchers have begun to investigate the phenomena of multimodality and micromobility. However, to date, existing research in this area has mainly focused on multimodality on a trip-level (i.e., intermodality), mainly through two effects: the integration effect and the substitution effect (Reck et al., 2022; Ricci, 2015; Wang et al., 2022).

On the one side, the integration effect refers to the potential of micromobility to complement other modes of transportation. Modal integration predominantly applies to individuals who use a micromobility device to cover the 'first-mile to' or the 'last-mile from' public transit (Oeschger et al., 2020), and has been explored using different methodologies. Following a survey approach, Adnan et al. (2019) and Fan et al. (2019) asked their respective respondents about their integration practices or preferences before and after the introduction of bicycle-sharing systems. Both sets of authors found that after bike-sharing introduction, shared bicycles became the preferred choice for first/last mile trips, followed by walking, private bicycles, and automobiles. In another study, Hamidi et al. (2019) developed an index to assess the role of a bike-sharing system in accessing the existing public transport network in Malmö, Sweden. Their findings illustrate that bike-sharing schemes are less likely to be extended to areas where people at higher risk of transport-related social exclusion live. In parallel, other authors have used big data from bike-sharing operators to identify start and end locations, trip duration, or user information (Böcker et al., 2020; Guo & He, 2020). Drawing on a complete two years trip record of the Oslo bike-sharing system, Böcker et al. (2020) analysed the potential use of bike-sharing for accessing, egressing, and interchanging public transport. Their results suggest that bike-sharing ridership is substantially higher on routes that either start or end with metro/rail connectivity, although they are less accessible by women and older population groups. In the case of e-scooters, research on the integration effect is less developed. In Austin, Texas, some studies analysed the relationships between land-use patterns and shared e-scooter usage, revealing that proximity to public transit nodes has a statistically significant and moderately positive impact on shared e-scooter ridership (S. Bai & Jiao, 2020; Caspi et al., 2020). More recently, an analysis from Madrid incorporated private e-scooters into their research question (Aguilera-García et al., 2024). Their results indicate a lower likelihood of adopting these private devices among people holding a public transportation pass, while regular access to car or motorcycle shows the opposite effect. According to the authors, this finding may indicate that individuals who own private e-scooters also tend to favour privately-owned vehicles over public transportation. Conversely, their findings show some higher degree of complementarity for sharing e-scooters and public transport. However, the authors acknowledge it remains uncertain whether shared e-scooters are primarily utilized as first/last mile mobility solutions to connect with the public transport network.

On the other side, the substitution effect refers to micromobility trips that replace trips formerly made by another mode of transport. Usually, these studies are based on counterfactual survey questions like *"Thinking about your last trip on a [micromobility mode under study], which mode of transport would you have taken if it had not existed?"* (Arellano & Fang, 2019a; Wang et al., 2022). The previous literature on micromobility acknowledged that emergent modes mostly substitute active and public transportation trips, while the effect on car users is limited (Felipe-Falgas et al., 2022; Fishman et al., 2013; Reck et al., 2022; Teixeira et al., 2021; Wang et al., 2022). This is especially remarkable for bike-sharing systems, for which substitution patterns have been confirmed across different geographical contexts, including Australia (Fishman et al., 2014), Ireland (Murphy & Usher, 2015), and Poland (Bieliński et al., 2021). While research on the substitution effects of e-scooters is still in an early stage, preliminary findings reached similar conclusions as those findings previously reached by bike-sharing studies. Studies conducted by Christoforou et al. (2021) in Paris (France) and Bai & Jiao (2020) in Austin (Texas, USA) suggest that e-scooters are often used for short trips, thus replacing walking, cycling, or public transit. In Vienna, Laa & Leth (2020) differentiated between two typologies of e-scooter users, owners and renters, and uncovered that whereas in both groups e-scooter trips mostly replaced walking and public transport, e-scooter owners showed a considerable mode-shift from private car trips. In the specific case of e-moped sharing systems, available studies are even more scarce. Taking Barcelona (Spain) as the case study, Roig-Costa et al. (2021) suggest that e-mopeds reached similar substitution rates as other micromobility devices. Overall, while substitution patterns across distinct micromobility vehicles are similar around the globe (higher level of substitution from active and public modes, and lower level of substitution from private modes), it is noteworthy that substitution rates vary considerably according to different mobility cultures. Indeed, several authors have suggested that substitution rates are related to contextual modal split. For example, the review addressed by Wang et al. (2022) shows that shared e-scooters users reported walking as being, effectively, the most commonly substituted travel mode. However, those authors note that substitution percentages range from 30 to 60% of trips, according to different cities. Similarly, in their reviews on bike-sharing determinants, Fishman et al. (2014), Reck et al. (2022) and Teixeira et al. (2020) suggest that higher proportions of shared bicycles substituting cars are generally found in contexts where the car represents a higher percentage in the modal share.

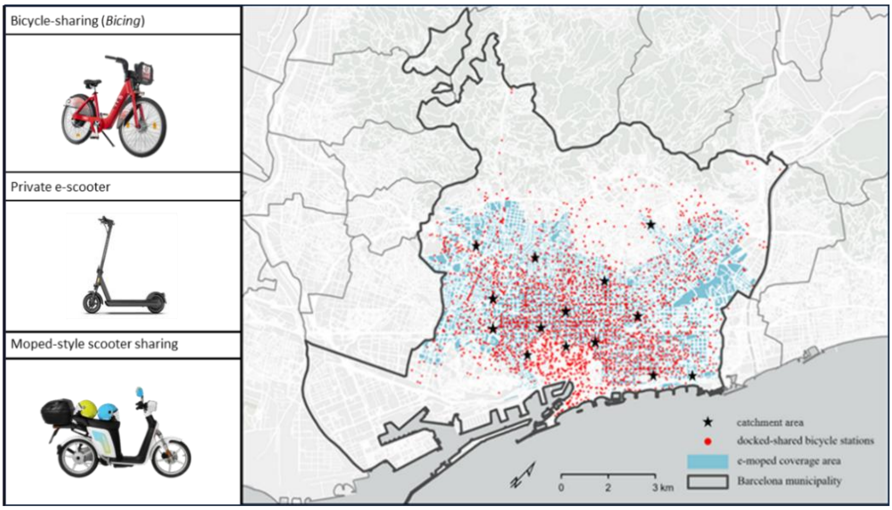
As previously noted, to gain a more comprehensive understanding of multimodality, a significant number of existing studies on traditional modes of transport tend to gather data that inform about travel behaviour for a period of one week and longer. However, when researchers have included micromobility as part of their multimodal mobility analyses, they have commonly used one-trip data. While these approaches provide valuable insights into the immediate and direct impacts of micromobility on mobility patterns, they miss long-term behavioural trends and habits of users, overlooking deeper integration patterns that might emerge only from observing a broader range of usage over time. In order to yield a more comprehensive analysis and to expand what the previous literature has already found regarding micromobility and the use of other transport modes, the present study evaluates the interaction between micromobility and traditional modes of transport within the frame of a complete week. Expanding the timespan can help in providing a more complete understanding of its impact on the transportation landscape and can also inform on future policy decisions.

### 4.1.3. Methodology

#### 4.1.3.1. Study area

The study took place in the municipality of Barcelona (1.6 million inhabitants), which is located in northeastern Spain (Map 3). The transport system of Barcelona offers 12 metro (underground) lines, 14 trains and 108 bus lines covering the whole municipality. The main mode of travel of the population in Barcelona is active mobility (57.2%), followed by public transport (24.0%), and private vehicles with 18.8% of weekday trips (EMEF, 2022). In terms of micromobility, the municipality has a public system of conventional- and electric-shared bicycles, under the operator known as *Bicing*, with a fleet of 7,000 bicycles (Soriguera & Jiménez-Meroño, 2020). Additionally, in 2021, the Barcelona City Council announced the regulation and licensing of moped-style sharing companies to operate within the city limits. Currently, the number of companies providing such services has reduced to nine, and the number of licenses to 5,407. Since 2017, shared e-scooters operated by private companies (e.g., Lime) are not allowed to operate within the city boundaries (Ajuntament de Barcelona, 2017). Consequently, the current e-scooter use in Barcelona is restricted to riding a privately-owned e-scooter, device that has emerged as a core micromobility component in the city (Roig-Costa et al., 2024b).

Map 3. Docked-shared bicycle stations and e-moped coverage area in the City of Barcelona




Source: own elaboration.

#### 4.1.3.2. Data collection and key variables

A questionnaire was disseminated in September 2020 using a computer-assisted personal interviews (CAPI) approach. Data collection was conducted by eight street interviewers, as detailed in Supplementary Table 1. In order to organise the fieldwork and obtain a sample of users circulating in different parts of the city, recruitment was conducted from 14 survey points covering nine out of ten city districts (Fig 1). To ensure homogeneity on the conducted interviews, interviewers were first trained in a session prior to the start of the data collection. As a measure of quality control, the research team of the study conducted three random street checks to ensure that interviewers were positioned within the designated influential areas and adhered to the established protocols. Participants were randomly intercepted in the street and at bike-sharing stations before or after the realisation of a micromobility trip, by using a convenience sampling approach. While this is a non-probabilistic sampling method (the only criterion was whether people were willing to participate), it is a cost-effective, faster, and easier way to collect data. In total, 902 micromobility users were interviewed. This paper uses data from the NEWMOB project, data that have been used in other studies (e.g., a life cycle assessment in Felipe-Falgas et al. (2022)). Our study will use the same data to explore weekly mobility patterns of micromobility users.

The questionnaire structure consisted of three blocks. The first block related to the respondents' socioeconomic characteristics and residence/workplace location variables. Socioeconomic characteristics included age, gender (*Woman, Man, Non-binary* or *Prefer not to say),* level of studies (*Primary or None, Secondary* or *University*), professional status (*Employed, Unemployed, Retired* or *Student*), and access to a car (*Yes* or *No*). Residence/workplace location variables included questions such as whether participants lived in Barcelona (*Yes* or *No*) and whether they worked with in Barcelona city boundaries (*Yes* or *No*). Table 5 shows some descriptive statistics for these variables. Both younger participants and men are overrepresented in our sample, but this is consistent with the sociodemographic profile of micromobility users in Barcelona (EMEF, 2022; IERMB, 2021), and in other Spanish urban areas (Aguilera-García et al., 2020).

Table 5. Sociodemographic characteristics of the sample (%).

| | | Private e-scooter (n=326) | Bicycle sharing systems (n=325) | E-moped sharing services (n=251) | Total sample (N=902) |
|---|---|---|---|---|---|
| Gender | Male | 63.5 | 53.6 | 69.1 | 61.6 |
| | Female | 35.9 | 45.5 | 29.9 | 37.7 |
| Age | *mean* | 31,33 | 31,9 | 29,5 | 31,0 |
| | *(std)* | (10,6) | (12,4) | (10,0) | (11,7) |
| Level of studies | University | 41.4 | 59.8 | 47.4 | 49.7 |
| | Secondary | 49.1 | 33.5 | 51.0 | 44.0 |
| | Primary or none | 9.5 | 6.7 | 1.5 | 6.2 |
| Professional status | Employed | 78.2 | 66.7 | 67.5 | 71.2 |
| | Student | 13.5 | 26.8 | 31.1 | 23.2 |
| | Unemployed | 5.8 | 5.2 | 1.4 | 4.2 |
| | Retired | 2.5 | 1.3 | 0.0 | 1.4 |
| Access to a car | (Yes) | 80.1 | 64.3 | 91.6 | 77.1 |
| Living in Bcn | (Yes) | 78.8 | 95 | 81.5 | 85.4 |
| Working in Bcn | (Yes) | 74.8 | 56.1 | 68.3 | 66.4 |

Source: Own elaboration.

The second block covered questions related to the usage frequency of the three micromobility devices of interest in this paper: private e-scooter, bicycle-sharing system, and e-moped sharing services. In particular, the question asked for each device was: *"In the last seven days, have you used the following micromobility mode of transport?"*[1]. Potential responses were (1) *Yes, 3 or more days*; (2) *Yes, 1 or 2 days*; and (3) *No, I have not.* For the purpose of this paper, these categories were renamed as (1) *Often*; (2) *Sometimes*; and (3) *Never.*

Finally, the third block consisted of questions regarding the frequency of use of traditional transport modes, such as private bicycle, metro, urban bus, train, private motorcycle, and private car. Similarly to the previous block, the

[1] This is a direct translation from Catalan, as the survey was collected in this language.

question was stated as follows: "*In the last seven days, have you used the following mode of transport?"*[2] with respondents having the possibility to answer either (1) *Yes, 3 or more days*; (2) *Yes, 1 or 2 days*; and (3) *No, I have not*. Again, categories were redefined as (1) *Often*; (2) *Sometimes*; and (3) *Never.* Walking was not included in this analysis as most individuals reported walking on most days, rendering the responses to this question somewhat redundant. Therefore, we decided that omitting walking would focus the analysis on differences in the usage of less universally frequent modes of transport. This methodological decision aligns with approaches taken by previous authors analysing monomodal and multimodal travel behaviour tendencies, such as those by Diana & Mokhtarian (2009) and Klinger (2017).

#### 4.1.3.3. Statistical analysis

The methodology followed a three-step approach. Firstly, cluster analyses were applied to identify homogeneous groups of micromobility users. Secondly, bivariate correlations were run between the clusters identified and the usage frequency of traditional transport modes (compiled in the questionnaire). Thirdly, a multinomial logistic regression model was performed to estimate the correlates of the six group of travellers.

Cluster analyses

Based on the above-mentioned questionnaire (Section 3.2), the frequency of use for each micromobility device (private e-scooter, bicycle-sharing system, and e-moped services) served as input for clustering individuals. Each cluster was made up of people with a similar micromobility travel behaviour. In view of the categorical nature of the data, the K-modes algorithm was chosen. The algorithm iterates reallocating objects until no changes of objects between

[2] This is a direct translation from Catalan, as the survey was collected in this language.

clusters are perceived. The K-modes algorithm was run in the klaR package of the R statistical computing environment, to obtain three, four, five, six and seven different clusters. Based on the preliminary data assessment, we focused on the solutions for 4, 5, and 6 clusters which indicated that these cluster sizes provided the most meaningful and interpretable groupings for our dataset. Finally, six clusters were taken for this study (895 observations, 99.2% of the cases) based on the average silhouette width test and the value of the silhouette coefficient. Values under 0.25 suggested the inability to establish a substantial consistency for the clusters; values between 0.26 and 0.50 suggested a weak and artificial cluster consistency; values ranging between 0.51 and 0.70 indicated a reasonable cluster consistency; and values higher than 0.71 denoted a strong cluster consistency.

Cluster bivariate associations

Bivariate analyses were carried out using the Fisher's Exact Test to explore each cluster's use of traditional means of transport. This helped in providing an accurate description of the complete modal mix of each cluster and confirmed the relationship between micromobility and traditional transport modes, which shed some light before applying multivariate methods. To reduce complexity, private car and private motorcycle were merged under the category *Private motorised vehicle*. In addition, traditional modes showing low frequencies of use were excluded from the analysis (e.g., electric private bicycle and electric private motorcycle). This helped in simplifying the analysis and reducing the complexity of the data, as including modes of transport with low usage frequencies did not contribute significantly to our research question.

Multivariate analysis of micromobility: multinomial logistic regression

A multinomial logistic regression analysis was used to identify the correlates of the six groups of travellers, taking Cluster 3 as the reference group. The independent variables comprised the frequency of use of traditional transport modes (e.g., own bicycle, metro, urban bus, train, private vehicle) while controlling for the sociodemographic attributes (age, gender, work status, level of education, access to car) and a residence related variable (city of residency). To avoid multicollinearity issues, the Spearman's rank correlation test was run for the independent variables. It was found that professional status and place of work were highly correlated ($p>0.7$), thus removing the latter from the analyses. The estimated equation was:

$$P(Y = k \mid X) = \frac{e^{(\beta_{0k}+\beta_{1k}X_1+\beta_{2k}X_2+...+\beta_{pk}X_p)}}{\sum_{j=1}^{K} e^{(\beta_{0j}+\beta_{1j}X_1+\beta_{2j}X_2+...+\beta_{pj}X_p)}}$$

where:

- $P(Y=k|X)$ is the probability of the outcome being in category $k$ given the predictors $X$. In the context of our study, the outcome variable Y represents membership to one of the different clusters, while categories $k$ represent the different clusters of micromobility users.
- $e$ is the base of the natural logarithm.
- $\beta 0k$, $\beta 1k$, $\beta 2k$, …, $\beta pk$β are the coefficients corresponding to each predictor variable for category $k$.
- $X1$, $X2$, …, $Xp$ are the predictor variables.
- The denominator is the sum of the exponentiated linear combinations of predictors for all categories. This ensures that the probabilities sum up to 1 across all categories.

Exp(B) -or odds ratio (OR)- and 95% confidence levels (CI) were computed for each Exp(B) value. The Exp(B) value is the predicted change in odds for a unit increase in the predictor variable. When Exp(B) is less than one, increasing values of the variable correspond to decreasing odds of belonging to a specific cluster compared to the reference group. Conversely, when Exp(B) is greater than one, increasing values of the predictor variable correspond to increasing odds of belonging to a specific cluster compared to the reference group. All variables were first tested one-by-one in unadjusted models. Variables that were independently associated with at least one cluster were then combined into the model. The multinomial logistic regression analysis was conducted using the NOMREG procedure in IBM SPSS Statistics version 21.

### 4.1.4. Results

#### 4.1.4.1. Cluster analysis

As mentioned in Section 3.3.1, a six-cluster solution proved to yield the best results. The average Silhouette width is 0.67, which indicates that the clusters presented a reasonable structure. The remainder of this section describes each cluster, as well as the frequency of use of the micromobility devices that are considered in this study (Table 6).

- Cluster 1 (*Bike-sharing lovers*): individuals within this cluster are frequent users of bicycle-sharing systems, while they never (or almost never) use private e-scooter or e-moped services. Silhouette coefficient is 0.81, which denotes a strong cluster consistency.
- Cluster 2 (*Trivial e-scooter users*): individuals within this cluster never (or almost never) use micromobility. If occasionally using

micromobility, they ride a private e-scooter. Silhouette coefficient is 0.68, which indicates a reasonable cluster consistency.

- Cluster 3 (*E-scooter enthusiasts*): individuals within this cluster are frequent users of a private e-scooter, while they never (or almost never) use bicycle-sharing systems or e-moped services. Silhouette coefficient is 0.78, which denotes a strong cluster consistency.
- Cluster 4 (*Casual bike-sharing users*): individuals within this cluster are occasional users of bicycle-sharing systems, while they never (or almost never) use private e-scooter or e-moped services. Silhouette coefficient is 0.42, which denotes a weak cluster consistency.
- Cluster 5 (*Casual e-moped users*): individuals within this cluster are occasional users of e-moped services. They never (or almost never) use other micromobility devices. Silhouette coefficient is 0.42, which denotes a weak cluster consistency.
- Cluster 6 (*E-moped enthusiasts*): individuals within this cluster are frequent users of e-moped services, while they never (or almost never) use other micromobility devices. Silhouette coefficient is 0.64, which denotes a reasonable cluster consistency.

It is noteworthy that the relatively weak silhouette coefficients observed for clusters 4 and 5 may stem from their status as occasional users of micromobility. Consequently, they do not have constant and clear micromobility behaviour, becoming “outliers” in our sample. This variability could introduce some degree of “noise” into the clustering process.

Table 6. Self-reported frequency of use of micromobility modes of transport (frequency in %).

| | 1. Bike-sharing lovers (22.2%) | 2. Trivial e-scooter users (11.0%) | 3. E-scooter enthusiasts (33.1%) | 4. Casual bike-sharing users (11.2%) | 5. Casual e-moped users (14.2%) | 6. E-moped enthusiasts (7.5%) | Sample average (99.2%) |
|---|---|---|---|---|---|---|---|
| Private e-scooter | | | | | | | |
| Often | **1.5** | **0.0** | **93.6** | **8.9** | **2.3** | **2.9** | 33.2 |
| Sometimes | 6.0 | **22.2** | 6.4 | 9.9 | 7.0 | 2.9 | 8.3 |
| Never | **92.5** | **77.8** | **0.0** | **81.2** | **90.6** | **94.1** | 58.5 |
| Shared bicycle | | | | | | | |
| Often | **100.0** | **0.0** | **1.0** | **0.0** | **10.2** | **5.9** | 24.6 |
| Sometimes | **0.0** | **0.0** | **2.7** | **100.0** | **7.8** | 11.8 | 14.2 |
| Never | **0.0** | **100.0** | **96.3** | **0.0** | **82.0** | **82.4** | 61.2 |
| E-moped sharing | | | | | | | |
| Often | **0.5** | **0.0** | **2.0** | **1.0** | **0.0** | **100.0** | 8.5 |
| Sometimes | **4.0** | **0.0** | **2.3** | **10.9** | **100.0** | **0.0** | 17.2 |
| Never | **95.5** | **100.0** | **95.7** | **88.1** | **0.0** | **0.0** | 74.3 |

Notes: Cluster shares are given in brackets. Numbers in bold indicate a statistically significant difference (Fisher Exact Test) compared to the overall distribution of the sample (p-value<0,05).
Source: Own elaboration

#### 4.1.4.2. Cluster bivariate associations

Bivariate associations were estimated between individuals included in each of the six clusters and their self-reported usage frequency of traditional transport modes (Table 7). Overall, two travel behaviour trends are identified. On the one side, clusters with a predominant monomodal travel behaviour (i.e., people who mainly rely on micromobility transport modes). Monomodal use is identified within Cluster 3 "*E-scooter enthusiasts*" and Cluster 6 "*E-moped enthusiasts*". Together, these clusters comprise more than 40% of the sample. On the other side, multimodal travellers combining micromobility with other traditional modes of transport are identified. Likewise, within multimodal users two profiles can be recognised: (i) multimodal users committed to public transport (e.g., Cluster 1 "*Bike-sharing lovers*", Cluster 2 "*Trivial e-scooter users*", and Cluster 4 "*Casual bike-sharing users*") and (ii) multimodal users who are dependent on private transport, being those participants who are included in Cluster 5 "*Casual e-moped users*". Within the first sub-group of multimodal travellers, micromobility ranges from being a pillar to being a complementary mode according to each cluster. For instance, users in Cluster 1, the so-called *Bike-sharing lovers*, rely mostly on bicycle-sharing systems to cover their mobility needs. However, while bicycle-sharing is a key component of their weekly mobility strategies, they still supplement their transportation needs with public transport modes, such as the metro and the bus. In contrast, Cluster 4, *Casual bike-sharing users*, use bicycle-sharing as a complementary mode of transport. Although they rely on short-term rental bicycles for certain mobility needs, in their case the metro is the primary mode of transportation around which their weekly mobility needs are organised. Similarly, Cluster 2, *Trivial e-scooter users*, are travellers who are mainly making use of public transport modes. However, in an occasional manner (we use the term 'trivial'), they complement their mobility needs by making use of a privately owned e-scooter. Within the second sub-group of multimodal travellers (i.e., those dependent on private transport modes), micromobility only plays a complementary role. Is the case of *Casual e-moped users* (Cluster 5), whose individuals are primarily private vehicle drivers who occasionally rent e-mopeds to supplement their weekly mobility needs.

Table 7. Self-reported frequency of use of other traditional modes of transport (frequency in %).

| | 1. Bike-sharing lovers (22.2%) | 2. Trivial e-scooter users (11.0%) | 3. E-scooter enthusiasts (33.1%) | 4. Casual bike-sharing users (11.2%) | 5. Casual e-moped users (14.2%) | 6. E-moped enthusiast s (7.5%) | Sample average (99.2%) |
|---|---|---|---|---|---|---|---|
| Own bicycle | | | | | | | |
| Often | 6.5 | 5.1 | 5.4 | 5.0 | 7.0 | 7.4 | 5.9 |
| Sometimes | **4.5** | 13.1 | 9.4 | 5.9 | **14.1** | 7.4 | 8.8 |
| Never | 89.0 | 81.8 | 85.3 | 89.1 | **78.9** | 85.3 | 85.3 |
| Private vehicle | | | | | | | |
| Often | **4.5** | 21.2 | **10.7** | 11.9 | **47.7** | 23.5 | 16.9 |
| Sometimes | **13.0** | 17.2 | 20.7 | 15.8 | 17.2 | 23.5 | 17.8 |
| Never | **82.5** | 61.6 | 68.6 | 72.3 | **35.2** | **52.9** | 65.4 |
| Metro | | | | | | | |
| Often | 19.5 | **29.3** | 14.0 | **31.7** | 15.6 | **8.8** | 18.8 |
| Sometimes | **48.5** | 35.4 | **26.1** | 33.7 | **25.0** | 29.4 | 33.1 |
| Never | **32.0** | **35.4** | **59.9** | **34.7** | **59.4** | **61.8** | 48.2 |
| Bus | | | | | | | |
| Often | 12.5 | **16.2** | **6.4** | 11.9 | 7.8 | 5.9 | 9.6 |
| Sometimes | **32.0** | 30.3 | **19.4** | **33.7** | 21.1 | 17.6 | 25.1 |
| Never | **55.5** | **53.5** | **74.2** | **54.5** | 71.1 | **76.5** | 65.3 |
| Train | | | | | | | |
| Often | 4.0 | 6.1 | 7.7 | 5.0 | 3.9 | 4.4 | 5.6 |
| Sometimes | 13.0 | **20.2** | **7.0** | 16.8 | 10.9 | 8.8 | 11.6 |
| Never | 83.0 | **73.7** | 85.3 | 78.2 | 85.2 | 86.8 | 82.8 |

Notes: Cluster shares are given in brackets. Numbers in bold indicate a statistically significant difference (Fisher Exact Test) compared to the overall distribution of the sample (p-value<0,05).
Source: own elaboration

#### 4.1.4.3. Micromobility multivariate analysis: multinomial logistic regression model

This section aims to provide a comprehensive analysis of the factors explaining the likelihood to belong to one of these six clusters using a multinomial logistic regression model (Table 8). The primary objective is to understand the characteristics and behaviours associated with each cluster, with Cluster 3, "E-scooter enthusiasts", serving as the reference group, as it represented the highest level of monomodal travel patterns, also being the largest cluster. By examining the multivariate associations between travel behaviours, sociodemographic factors, and cluster membership, we uncover the underlying patterns that differentiate various micromobility users.

Cluster 1 "*Bike-sharing lovers*" versus Cluster 3 "*E-scooter enthusiasts*".

Among the use of traditional modes of transport, it is confirmed that an occasional metro use increased the odds of belonging to Cluster 1 "Bike-sharing lovers" compared with the referent Cluster 3. Living within Barcelona city boundaries increased the odds of belonging to Cluster 1, by almost 5 times (4.909). As for sociodemographic factors, being a student and holding a university degree strongly increased the odds of belonging to Cluster 1, while being a woman and a year older slightly increased the odds of belonging to Cluster 1. In contrast, having access to car decreased by more almost 50% the odds of belonging to Cluster 1.

Cluster 2 "*Trivial e-scooter users"* versus Cluster 3 "*E-scooter enthusiasts*".

Among the use of public modes of transportation, regular and casual uses of the metro, on the one side, and an occasional use of the train, on the other side, increased the likelihood of belonging to Cluster 2, compared to Cluster 3. In addition, a regular use of private modes increased the likelihood of belonging to Cluster 2. As for sociodemographic factors, being a student and holding a university degree increased the odds of belonging to Cluster 2. In contrast, Cluster 2 presented the same association with having access to car, as Cluster 1 compared to Cluster 3.

Cluster 4 *"Casual bike-sharing users"* versus Cluster 3 *"E-scooter enthusiasts".*

A regular and an occasional use of metro usage were associated with an increase in the odds of being in Cluster 4 compared with Cluster 3. Additionally, a frequent use of private modes increased the likelihood of belonging to Cluster 4. Living within Barcelona city boundaries strongly increased the odds of belonging to Cluster 4, by more than 10 times. As for sociodemographic factors, being a student and being highly educated increased the odds of belonging to Cluster 4. In contrast, having access to car decreased the likelihood of belonging to Cluster 4, compared to Cluster 3.

Cluster 5 *"Casual e-moped user"* versus Cluster 3 *"E-scooter enthusiasts".*

Among the use of traditional modes of transport, a frequent use of private modes of transport was highly associated with an increase in the odds of being in Cluster 6 compared with Cluster 3. Additionally, being a student and specially holding a university degree increased the odds of belonging to Cluster 6.

Cluster 6 *"E-moped enthusiasts"* versus Cluster 3 *"E-scooter enthusiasts".*

Among the use of traditional modes of transport, an occasional use of metropolitan public transport modes such as the train and a regular use of private modes of transport was associated with an increase in the odds of being in Cluster 6 compared with Cluster 3. Additionally, living within Barcelona city boundaries also increased the odds of belonging to Cluster 6.

Taula 8. Adjusted associations between the frequency of use of traditional modes of transportation, socioeconomic characteristics, locational variables, and clusters of micromobility travel behaviors. Multinomial logistic regression model (Reference = Cluster 3 “E-scooter lovers”).

| | | Cluster 1. Bike-sharing lovers | | | Cluster 2. Trivial e-scooter users | | | Cluster 4. Casual Bike-sharing users | | | Cluster 5. Casual e-moped users | | | Cluster 6. E-moped enthusiasts | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | B (S.E.) | OR Exp(B) | CI 95% | B (S.E.) | OR Exp(B) | CI 95% | B (S.E.) | OR Exp(B) | CI 95% | B (S.E.) | OR Exp(B) | CI 95% | B (S.E.) | OR Exp(B) | CI 95% |
| Use of own bicycle (ref=never) | Often | 0,360 (0,420) | 1,433 | (0,629; 3,263) | 0,165 (0,556) | 1,180 | (0,397; 3,507) | 0,044 (0,555) | 1,045 | (0,352; 3,102) | 0,446 (0,472) | 1,562 | (0,62; 3,938) | 0,340 (0,550) | 1,406 | (0,479; 4,129) |
| | Sometimes | -0,748 (0,417) | ,473 | (0,209; 1,072) | 0,300 (0,397) | 1,350 | (0,62; 2,94) | -0,733 (0,524) | ,480 | (0,172; 1,342) | 0,466 (0,359) | 1,593 | (0,788; 3,222) | -0,147 (0,520) | ,863 | (0,311; 2,391) |
| Use of metro (ref=never) | Often | 0,612 (0,321) | 1,844 | (0,982; 3,462) | 1,071 (0,377) | 2,918** | (1,393; 6,11) | 1,214 (0,373) | 3,365** | (1,621; 6,986) | 0,617 (0,382) | 1,853 | (0,876; 3,918) | -0,501 (0,527) | ,606 | (0,215; 1,703) |
| | Sometimes | 1,081 (0,236) | 2,948*** | (1,857; 4,68) | 0,851 (0,307) | 2,343** | (1,283; 4,279) | 0,714 (0,308) | 2,043* | (1,116; 3,739) | 0,321 (0,291) | 1,378 | (0,779; 2,438) | 0,168 (0,343) | 1,184 | (0,604; 2,318) |
| Use of bus (ref=never) | Often | 0,723 (0,385) | 2,061 | (0,969; 4,385) | 0,818 (0,439) | 2,266 | (0,959; 5,357) | 0,523 (0,476) | 1,687 | (0,664; 4,29) | 0,545 (0,478) | 1,724 | (0,676; 4,396) | 0,387 (0,628) | 1,472 | (0,43; 5,041) |
| | Sometimes | 0,368 (0,249) | 1,446 | (0,887; 2,356) | 0,357 (0,313) | 1,429 | (0,774; 2,636) | 0,590 (0,305) | 1,804 | (0,992; 3,281) | 0,198 (0,307) | 1,219 | (0,667; 2,226) | -0,123 (0,401) | ,885 | (0,403; 1,94) |
| Use of train (ref=never) | Often | 0,257 (0,321) | 1,293 | (0,69; 2,424) | -0,278 (0,414) | ,757 | (0,336; 1,705) | 0,109 (0,403) | 1,115 | (0,506; 2,457) | -0,450 (0,423) | ,638 | (0,279; 1,46) | 0,490 (0,473) | 1,633 | (0,646; 4,131) |
| | Sometimes | 0,278 (0,323) | 1,320 | (0,702; 2,485) | 0,791 (0,355) | 2,205* | (1,1; 4,42) | 0,000 (0,402) | 1,000 | (0,454; 2,199) | 0,490 (0,356) | 1,632 | (0,812; 3,28) | 0,865 (0,429) | 2,374* | (1,025; 5,499) |
| Use of private mode (ref=never) | Often | -0,452 (0,422) | ,636 | (0,278; 1,456) | 1,377 (0,376) | 3,964*** | (1,896; 8,288) | 0,831 (0,425) | 2,296* | (1,018; 5,178) | 2,192 (0,315) | 8,949*** | (4,83; 16,584) | 0,992 (0,408) | 2,696* | (1,211; 6,002) |

| | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Sometimes | -0,420 (0,285) | ,657 | (0,376; 1,15) | 0,295 (0,353) | 1,344 | (0,673; 2,685) | 0,070 (0,352) | 1,073 | (0,538; 2,14) | 0,417 (0,322) | 1,518 | (0,808; 2,851) | 0,396 (0,361) | 1,485 | (0,732; 3,016) |
| City of residence (ref=no Barcelona) | Barcelona | 1,591 (0,364) | 4,909*** | (2,404; 10,026) | 0,441 (0,344) | 1,554 | (0,792; 3,052) | 2,359 (0,633) | 10,581*** | (3,057; 36,617) | 0,389 (0,319) | 1,476 | (0,79; 2,757) | 1,326 (0,487) | 3,766** | (1,45; 9,783) |
| Age | | 0,022 (0,011) | 1,022* | (1,001; 1,044) | 0,022 (0,014) | 1,022 | (0,994; 1,051) | 0,014 (0,014) | 1,015 | (0,988; 1,042) | -0,003 (0,013) | ,997 | (0,972; 1,022) | -0,018 (0,016) | ,983 | (0,952; 1,014) |
| Gender (ref=man) | Woman | 0,439 (0,206) | 1,551* | (1,036; 2,322) | 0,096 (0,264) | 1,100 | (0,655; 1,848) | 0,011 (0,263) | 1,011 | (0,604; 1,692) | -0,190 (0,253) | ,827 | (0,504; 1,357) | -0,574 (0,322) | ,563 | (0,299; 1,06) |
| Professional situation (ref=employed) | Student | 1,394 (0,310) | 4,030*** | (2,196; 7,394) | 1,645 (0,374) | 5,183*** | (2,489; 10,791) | 1,065 (0,388) | 2,900** | (1,356; 6,204) | 0,870 (0,356) | 2,386* | (1,187; 4,796) | -0,170 (0,437) | ,843 | (0,358; 1,988) |
| | Other | -0,013 (0,403) | ,987 | (0,448; 2,177) | -0,706 (0,662) | ,494 | (0,135; 1,808) | -0,413 (0,553) | ,662 | (0,224; 1,955) | -0,726 (0,605) | ,484 | (0,148; 1,582) | - 20,769 (0,000) | ,000 | (0,000; 0,000) |
| Level of studies (ref=no university) | University | 0,877 (0,219) | 2,403*** | (1,566; 3,688) | 0,651 (0,282) | 1,917* | (1,102; 3,336) | 1,098 (0,282) | 2,997*** | (1,725; 5,206) | 0,816 (0,258) | 2,261** | (1,363; 3,752) | -0,228 (0,304) | ,796 | (0,438; 1,446) |
| Access to car (ref=no) | Yes | -0,656 (0,248) | 0,519** | (0,319; 0,844) | -0,663 (0,324) | 0,515* | (0,273; 0,973) | -0,899 (0,310) | 0,407** | (0,222; 0,748) | 0,398 (0,400) | 1,488 | (0,679; 3,262) | 0,191 (0,440) | 1,210 | (0,51; 2,869) |

Notes: Pseudo R (Nagelkerke)=0,359; * p-value<0,10; ** p-value <0.05; *** p-value < 0,001; B (S.E.): coefficient (standard error); OR: odds ratio; CI: confidence interval.

Source: own elaboration

### 4.1.5. Discussion

Often presented as an alternative to traditional modes of transport, micromobility has expanded the number of transportation options available to urban travellers. However, despite its increasing popularity, it remains unclear whether its deployment in urban ecosystems has triggered more or less sustainable travel patterns. The present study explores whether micromobility users in Barcelona have preferences towards monomodal or multimodal travel behaviours. Through an analysis of how frequently do micromobility users opt for traditional transportation modes, we investigated how micromobility modes fits into the wider transportation mix, gaining insights into the specific patterns of multimodality among micromobility users.From the supply side, Barcelona presents a variety of micromobility options that offer a wide set of choices to travellers, ranging from public bike-sharing systems to moped-sharing services (Bach et al., 2023a; Bretones & Marquet, 2023; Roig-Costa et al., 2021). Nonetheless, and contrary to our initial hypothesis (H1), our results show that micromobility users are essentially attached to a single micromobility device, showing almost no interest for other micromobility alternatives. This means, for instance, that most e-scooter users in our sample were unlikely to use any other micromobility mode during their everyday travel. Similarly, users of bicycle-sharing systems hardly ever used any other micromobility mode. In fact, multimodality within micromobility is almost non-existent, as virtually no participants declared using a combination of e-scooter, bike-sharing, and/or e-moped during the week. In the specific case of e-scooters, this inexistent combination with other micromobility alternatives was already anticipated by hypothesis 1 (H1) and may be explained by the fact that e-scooters in Barcelona can only be privately owned. In this case, owning the device may act as a mechanism reinforcing its usage (Klinger, 2017), reducing the necessity to consider other micromobility options. However, given the shared features of both systems, we expected a larger overlap in user coverage between shared bikes and shared e-mopeds than was observed. These findings contradict previous studies suggesting that moped-sharing services may complement other shared mobility options, such as bike-sharing (Aguilera-García et al., 2021), and call into question the ability of e-moped services to act a gateway to encourage the adoption of other micromobility modes (Bach et al., 2023). At the modal mix level, our week-based analysis has revealed a greater variance than previous trip-based analyses. This aligns with multimodality studies focusing exclusively on traditional modes of transport, which found that longer time periods captured a wider variability of profiles (Buehler & Hamre, 2016; Kuhnimhof et al., 2012). Our findings indicate that while micromobility users rarely switch between micromobility modes, they do engage in multimodal behaviour with traditional modes of transport, displaying a diverse modal mix. This is consistent with the trends described in the study by Klinger (2017), who found that the traditional classification of users as either solely car-drivers or users exclusively preferring sustainable modes of transport was somewhat obsolete. According to that study, individuals tend to make decisions about the most appropriate mode of transport in a more pragmatic way, based on a situational rationale. Similarly, our results show that for some users, micromobility constitutes their core mode of transportation, while for others it merely represents an additional or complementary option within their weekly modal mixes. These findings support a more flexible understanding of traveller typologies and travel choice behaviours.

In line with this, our findings show that different typologies of micromobility options trigger distinct modal patterns. To the best of our knowledge, the present study is among the first to find a strong association between e-scooter and monomodal behaviours, as anticipated in our second hypothesis (H2).

However, this result is consistent with previous findings by Diana & Mokhtarian (2009) and Garcia-Sierra et al. (2018), who established a clear association between vehicle ownership and monomodal tendencies. Related to this, prior research had also found that entering professional life drastically attenuates multimodal behaviours (Nobis, 2007). In a life-stage where daily routines become more complex, the inherent characteristics of the daily commute, such as fixed distances, routes, schedules, or frequencies, make occupational trips the kind of trip that is most significantly influenced by habits (Kun Gao et al., 2020). Our results seem to reflect this, showing that employed individuals are characterised by an intensive monomodal use of micromobility modes, especially private e-scooter, and tend to have lower multimodality rates. The specific context of Barcelona, where the city council effectively banned sharing e-scooter services, pushing individuals to buy their own e-scooter, may be affecting these results (Roig-Costa et al., 2024b). The combination of private ownership plus the convenient features of e-scooters - small and lightweight- allows for easy door-to-door travel and may create a greater degree of owner attachment to the device, reducing any incentive to use other modes of transport. In this sense, the behaviour of private e-scooter owners might be more similar to that of motorcycle owners (Marquet & Miralles-Guasch, 2016), rather than traditional private bicycle owners, who exhibit slightly more multimodal tendencies across various contexts (Fu et al., 2024; Olafsson et al., 2016).

However, a relation of exclusivity and dependence with a single mode can be problematic in the long term, especially when the micromobility device in question is not available (due to maintenance issues, for instance), or when circumstances make its usage unsuitable (longer trips, trips to areas without adequate infrastructure, adverse weather conditions, or while carrying heavy loads). A lack of flexibility in switching to alternative modes of transportation could eventually lead to increments in immobility rates or, as suggested by Haworth et al. (2021), to misuses or risky behaviours. In this respect, policymakers should promote the attractiveness and efficiency of public transport, both in combination with and independent of these small devices. This would encourage more rational and safe mobility choices, particularly in situations where door-to-door e-scooter travel is not feasible or advisable. Additionally, as seen with other mobility options, repetitive and exclusive use of a particular mode of transport can lead to a lack of consideration for other users with whom e-scooters have to share space. In Barcelona, for example, motorcycle riders who exhibit high levels of monomodality (Marquet & Miralles-Guasch, 2016), are frequently observed parking on pedestrian areas, which creates hazards for pedestrians (Catalunya Camina & Eixample Respira, 2022), or driving in the bus lanes, which results in slowing down bus traffic. Similarly, e-scooter users entrenched in monomodal habits might more easily engage in unsafe or inconsiderate practices such as riding on sidewalks (Haworth et al., 2021). As suggested by (Gibson et al., 2022), more research is needed to better understand the travel behaviour associated with such a monomodal device, especially when the device does not fit neatly into a specific category and violations of transport space boundaries can threaten both the integrity of the e-scooter riders themselves and the safety of pedestrians (Ma et al., 2021; Sikka et al., 2019).

In contrast, as also anticipated in our second hypothesis (H2), sharing services in our study appear to be associated with more multimodal weekly patterns. Among our sample, bicycle-sharing users show a higher disposition to using other modes of transport other than micromobility. Consistent with the body of literature, our results indicate that a change in the transportation culture towards more frequent use of sharing systems and lower ownership rates might be expanding the set of modes of transport that travellers rely on, on a weekly basis (Miramontes et al., 2017). In Barcelona, bicycle-sharing has become both a pillar for some users' daily mobility strategies, and a flexible and convenient mode of transportation that complements other options for others. Aligning with previous research (Levy, 2013; Roberts et al., 2011), our findings reveal that female micromobility users tend to use the widest variety of modes of transport on a weekly basis, and interestingly, they seem to be more likely to rely on a public sharing system (i.e. bike sharing system) as the backbone of their mobility strategies. This finding might be explained by the greater variance in the characteristics of their trips, as women tend to travel shorter distances and make more unplanned trips for personal and household purposes (Maciejewska et al., 2019b; Maciejewska & Miralles-Guasch, 2020), trip characteristics ideally accommodated by the flexibility and accessibility of bike-sharing systems. Therefore, the success of bike-sharing systems might be creating a group of multimodal users that are able to choose their mode of transportation based on their real-time needs and contexts, making modal choice a more rational process potentially less dependent on habit, which women might be taking good advantage of. This represents a departure point from the traditional approach of choosing a mode of transportation for the entire day, allowing users to select the most suitable mode of transportation for each individual trip that they need to make.

In parallel, multimodal tendencies are also observed within users relying on solutions provided by private sharing operators. Barcelona is a city with a long-standing tradition of using private mopeds and motorcycles for urban transport (Marquet & Miralles-Guasch, 2016). Because of that, shared moped-style systems are thought to have much appeal and potential to expand and, thus, have started to attract the attention of a number of studies (Bach et al., 2023a; Bach et al., 2023b). According to our results, a great proportion of users who pay for on-demand e-moped sharing services primarily rely on car/motorcycle-trips and only use shared mopeds on an occasional basis. This is consistent with the work of Aguilera-García et al. (2020), who identified a positive association between car ownership and shared-moped use in Madrid, suggesting that shared moped systems in Spain, in general, might be viewed as a "crutch" vehicle that offers the benefits of a motorised private vehicle without the problems and burdens of the ownership. The results of their study also suggest that moped sharing services may be complementing rather than replacing private vehicle ownership. In fact, in relation to that, when adjusting for all the correlates in our multinomial model, results in our study show that even the specific subset of e-moped enthusiasts initially depicted as exclusively monomodal users tend to rely on private modes of transportation for some of their mobility needs. This confirms that e-moped sharing systems are associated with multimodal travel patterns and reveals a worrisome disconnection between e-moped usages and urban public transport modes. While shared mopeds are certainly a step in the right direction towards more sustainable transportation options, they may not be sufficient to trigger deep changes in travel behaviour.

In contrast, one association that the introduction of micromobility may have significantly altered is the link between multimodality and socioeconomic backgrounds. Traditionally, the use of multiple modes of transportation, which requires considerable effort and extensive information for effective geographic and temporal travel organization (Nobis, 2007), has been associated to low-income population groups (Diana & Mokhtarian, 2009; Kroesen, 2014b; Molin et al., 2016). Although context-dependent, multimodality has generally been perceived as a burden, leading to experiences of transport inadequacies and reduced accessibility (Fu et al., 2024). Consequently, high-income populations are often unwilling to incur the complexities and the costs associated with multi-option mobility schemes. Previous studies, for instance, have tested the relationship between the number of household vehicles -which might be a proxy of income- and multimodality, showing that people having more household vehicles have a higher possibility of being monomodal car user (Buehler & Hamre, 2016; Maciejewska et al., 2023). However, our models consistently find higher socioeconomic profiles to be associated with a higher multimodal behaviour, while lower profiles appear to be skewed to monomodal practices. The introduction and access to diverse micromobility options may be significantly simplifying the complexities and uncertainties of mobility-planning, alleviating the need to rigidly plan out transportation strategies far in advance.

However, this ability of some micromobility services to break well-established theories on urban travel behaviour may be partially explained by Barcelona's bicycle-sharing system layout and e-moped services coverage area, which operates exclusively within the Barcelona city boundaries and thus concentrates its network mostly in central areas of the city. In fact, what these findings may be highlighting is the role of shared micromobility services in exacerbating existing transportation inequalities based on socioeconomic status, with higher-income individuals benefiting more from the increased travel choices. Conversely, lower-income individuals are potentially left behind with fewer options, leading them opt for e-scooter ownership, which entails a monomodal behaviour. As others have anticipated, shared options are scarcer in the outskirts of the cities, which might be translating into more intensive use of private micromobility options (Aguilera-García et al., 2024). This finding suggests that for micromobility to have a real ability to break well-established theories on urban travel behaviour, policy interventions should first ensure micromobility accessibility and affordability for all income groups, rather than solely benefiting those who are already better off (Spinney, 2020a).

Finally, the possibility to access a diversified range of micromobility options may be reducing the reliance on any single mode of transport, boosting more rational travel behaviour choices but also mitigating risks associated to eventual disruptions, schedule changes, or even low or null public transport offer at certain times of the day. Ultimately, in contingency scenarios, micromobility's inherent cost-effectiveness becomes even more pronounced, offering a substantial advantage over more traditional transport modes commonly associated to unexpected scenarios, such as taxis or more recently introduced ride-haling platforms like Uber or Cabify (De Souza Silva et al., 2018). This advantage is key not only in reducing economic burdens, enhancing accessibility, or improving the ease of mobility for urban dwellers at critical times, but also for reducing externalities such as air pollution and congestion (Tirachini, 2020), thus enhancing urban sustainability. However, the lack of centralised information across travel modes might be slowing down the maximisation of this potential. If transportation suppliers succeeded in reducing both the uneven accessibility levels across groups of population and the fragmentation in the access to information, the use of bicycles on an as-needed basis could arise as a convenient option with which to meet weekly transport demand of people with different cycling preferences and expectations. As previous authors have noted (Arias-Molinares & Carlos García-Palomares, 2020; H. Becker et al., 2020), a plausible way of simplifying the provision of information and access to information is to create a unique common information source in the form of a Mobility as a Service (MaaS). Developing a digital channel enabling users to book for multiple types of mobility services (buses, trams, subways, and bike-sharing options now operated by different entities and accessed through different systems) could help boosting the potential to use bike-sharing for multimodality and unplanned trips. This integration would improve the experience of travellers already opting for sustainable choices and likely contribute to the shift from motorized private modes of transportation to sustainable options.

### 4.1.6. Conclusions

This study has addressed weekly multimodal travel behaviour among micromobility users. We have studied whether, and to what extent, individuals combine different types of micromobility devices or combine micromobility use with traditional modes of transport. This is important, in order to (1) understand the potential benefits that an integration of these new modes of transport could bring into the whole transportation system, and (2) to assess to what extent a higher number of transportation options would translate into more rational travel behaviour choices. For that purpose, we used cluster techniques to identify six clusters of micromobility users: (1) Bike-sharing lovers, (2) Trivial e-scooter users, (3) E-scooter enthusiasts, (4) Casual bike-sharing users, (5) Casual e-moped users, and (6) E-moped enthusiasts. Our findings, in the first instance, have demonstrated that individuals using micromobility options exhibit a clear preference for a single type of device, while not engaging in the complementary use of alternative micromobility modes. At the same time, they highlight the heterogeneity of the function of each micromobility alternative across different groups of users' weekly mobility patterns. While some users demonstrate a tendency towards monomodality and rely solely on micromobility as a pillar and exclusive component of their mobility strategy (Cluster 3 and, to a lesser extent, Cluster 6), others exhibit weekly multimodal travel patterns where micromobility plays both a pillar role (Cluster 1) and a complementary role (Clusters 2, 4 and 5).

This study is not without limitations. Firstly, the utilisation of a non-probabilistic sampling technique, followed by a random intercept mechanism, limits our study's ability to extrapolate our findings to the entire municipality of Barcelona. However, to ensure the representativeness of our sample, we undertook a validation exercise using alternative data sources, revealing that the demographic characteristics of our sample, including gender and age, align with those of the broader population utilising micromobility within the city. Secondly, the authors acknowledge that the data collection occurred during a uniquely atypical global traffic situation caused by the COVID-19 pandemic, which necessitates cautious interpretation of the results. However, restrictions in Spain changed from wave to wave and specially in between waves. On June 21, 2020, the first state of alarm ended and the whole country officially entered the phase of "new normality". It was not until October 25, 2020, that the Government declared the second state of alarm. Therefore, during the second half of September 2020, when our project data gathering took place, the country had been in the "new normality" for more than 3 months. Travel restrictions were way more relaxed compared to the previous months and the urban transportation dynamics more normalized. Therefore, we think that the potential bias of replies is much lower than compared with other COVID-19 windows. Finally, future research must consider making a distinction between mechanical and electric bicycle-sharing, as more accurate profiles and modal mixes would appear from the analysis.

In conclusion, our findings help to better understand micromobility behaviour in all of their complexities, and to depicting micromobility users not as a monolithic community. Without a deep understanding of micromobility multimodality, cities are left to plan based on trial and error, resulting in inefficient and often unsustainable infrastructure. For the future, more research is needed to better understand how and why different modes are used, and whether these decisions are based on habit or are made on a trip-to-trip basis.

## 4.2. Shared bikes vs. private e-scooters. Understanding patterns of use and demand in a policy-constrained micromobility environment

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### Shared bikes vs. private e-scooters. Understanding patterns of use and demand in a policy-constrained micromobility environment

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A R T I C L E  I N F O

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A B S T R A C T

Urban mobility has undergone a transformation with the advent of micromobility vehicles, leading to a multitude of studies investigating the factors that drive early adoption and the sustainability and equity implications. However, in a context where local administrations struggle regarding how to fit different micromobility systems within the urban ecosystem, little is understood about how political regulations impact micromobility users' modal choices This study aims to shed light on the differences between private e-scooters and shared bikes in Barcelona, a city where micromobility options face distinct regulatory frameworks, and also to understand the factors that influence an individual's choice between these two modes of micromobility. The study employs a self-reported intercept survey on 651 micromobility users and builds a logistic binary regression model to examine the characteristics that differentiate e-scooter and shared bike adopters. Results indicate notable differences between adopters of the two modes and suggest that city regulations might play a role in determining the choice of mode. Furthermore, the study finds that while both modes follow similar mode replacement paths, shared bikes have a higher potential to keep users away from cars. These findings contribute to the limited knowledge on the choice between different modes of micromobility and highlight the impact of policy design on diverse population groups. As more cities are banning free-floating from city centres, it is essential to understand how these selective bans and restrictive policies have an impact on micromobility users' modal choices.

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### 4.2.1. Introduction

In recent years, there has been the introduction of a myriad of electric devices and new-shared transportation options offering the promise of a new, cleaner, and more dynamic transportation system, with all of them falling under the vast concept of “micromobility”. These new forms of transport have been tolerated, or even promoted, worldwide under the premise that they might help the transition towards a cleaner and more sustainable transportation system, as well as potentially improving transport equity by providing cheap and easy access to basic mobility options. The potential for these new modes of transport to aid climate change efforts or generate more equitable transport systems, however, remains under debate. To better understand the impact of micromobility on current transportation systems it is imperative to conduct comprehensive research and analysis of the various factors involved. Hence, gaining insight into the patterns of use and demand of specific micromobility solution, has become more important than ever. This paper contributes to the discussion by focusing on the case of Barcelona, a city with an effervescent and particular micromobility environment that can serve as a reference point for the challenges that other cities might face in the future.

As cities continue to experience increasing levels of population and congestion, many individuals are seeking out alternative forms of personal transportation. Two of the major exponents of these emergent mobility devices in European urban environments include e-scooters and docked-BSS (bike-sharing systems). While they are often grouped under the same umbrella of alternative transportation, e-scooters and shared bikes have distinct impacts on the overall transportation system. Their differing speeds and rates of acceleration differentiate their behaviour on the streets, forcing the other users to adapt and cope in different ways (Cubells et al., 2023b). Moreover, their distinct physical characteristics require a different transport infrastructure, including varying street surface, street network, and road design (Glavic et al., 2021). Specifically, e-scooters are defined as *scooters with a standing design with a handlebar, deck, and wheels that are propelled by an electric motor* (Shaheen & Cohen, 2019), while docked-BSS are defined as those systems that offer *either conventional or electric bicycles to enable short-term rental from one docking station to another* (Fishman et al., 2013).

The major interest in these new modes of transport has resulted in an already significant body of literature examining the determinants of its early adoption, including the sociodemographic characteristics of users, their beliefs and perceptions, and the motivations explaining their modal choice (Ampudia-Renuncio et al., 2018; Becker & Rudolf, 2018; Burghard & Dütschke, 2019; Fishman, 2016; Laa & Leth, 2020; W. Li & Kamargianni, 2018). Surprisingly, however, these studies tend to address micromobility as a homogenic block, or select only one of the multiple modes that fall within the micromobility definition (Fishman et al., 2013; Jiao & Bai, 2020). As a result, there exists a lack of studies addressing the key determinants that may influence the choice of one micromobility mode over another. In other words, little is known about why an individual who is willing to use a micromobility device, ends up choosing a bike over an e-scooter, or vice versa. Understanding these factors is even more important when different modes of transport do not share the same mobility operating system. This is the case in cities where one can find an established bike sharing system, but not an e-scooter sharing system. In these cases, uncovering the factors leading people towards the shared system over the privately-owned system is key in guaranteeing the success of the public alternative. Shedding light on the elements influencing modal choice within micromobility options can also help in understanding the specific role of each micromobility device and its contribution to the overall transport system. This research topic is particularly important when the issue under debate is micromobility's potential to promote fairer and more equitable transport systems.

This paper is aimed at understanding what drives users towards privately-owned e-scooters over shared bikes, and which factors are involved in each specific modal choice. This study uses data from a travel survey conducted in Barcelona, Spain and is based on a four-step analysis: (1) an exploration of the user profile of each of the two most well-known micromobility alternatives in Barcelona; (2) an examination of the most prominent socioeconomic and mobile predictors explaining private e-scooter usage as a modal choice over BSS usage; (3) a description of the origin of the demand of each of the micromobility modes; and (4) an exploration of the subjective evaluation of private e-scooter and BSS users. The remainder of the paper is structured as follows. Section 2 reviews the determinants of micromobility modes, in addition to examining the few urban settings that share similar micromobility frameworks with Barcelona. Section 3 presents the study area, the data collection process, and a description of the methodology used. Section 4 provides the main results, while Section 5 discusses those results, and includes a reflection on the impact of political decisions on the degree of popularisation of different micromobility options. Finally, the conclusions and study limitations can be found in Section 6.

### 4.2.2. Background

#### 4.2.2.1. Micromobility adoption: characteristics, impacts, and motivations

Micromobility has already become a trend in the mobility and transportation literature (Abduljabbar et al., 2021; Elmashhara et al., 2022; Fulton, 2018; Mouratidis, 2022). Although it is a young research field, most studies identify a common set of demographic and socioeconomic factors that are shared by different types of micromobility devices. Typically, micromobility users are young, highly-educated males with full-time employment (Mckenzie, 2019; Mouratidis, 2022; Reck & Axhausen, 2021; Shaheen & Cohen, 2019). However, despite these common traits, the previous body of literature has acknowledged nuances across distinct devices. In terms of gender, for instance, greater imbalances are commonly found among e-scooter riders (Hosseinzadeh et al., 2021c; Jiao & Bai, 2020; Nikiforiadis et al., 2021; Sanders et al., 2020) than among bike-sharing users (Goodman et al., 2014; Mouratidis, 2022; Roig-Costa et al., 2021). Slight differences across devices can also be found regarding socioeconomic characteristics. On the one hand, in the case regarding bike-sharing, a vast majority of the previous literature agrees that users tend to have higher levels of education (Ricci, 2015; Shaheen et al., 2014). However, this clear consensus does not exist regarding e-scooters. In this case, while some studies have found a more prevalent use of e-scooters in neighbourhoods with highly educated people (Bai & Jiao, 2020; Clewlow & Mishra, 2017; Merlin et al., 2021), associations between higher levels of education and a higher degree of riding are not supported by other studies (Mitra & Hess, 2021). Other factors that seem to be associated to micromobility use are ownership of a driving license, or having access to a private car. However, these associations seem to be dependent on the context, as the literature has reached indistinctly perceived conclusions, in the case for bike-sharing (Bielinski & Wazna, 2020; Eren & Uz, 2020) and also in the case for e-scooter usage (Blazanin et al., 2022; Mouratidis, 2022; Reck & Axhausen, 2021).

In contrast, an issue that the literature generally agrees on is the fact that micromobility's introduction impact is highly conditional on the type of vehicle that all these new transport modes are replacing. Multiple studies concur in finding that any reduction in the negative environmental and social externalities that are associated with transport are only truly achieved when the modal change involves replacing automobiles (Felipe-Falgas et al., 2022; Hollingsworth et al., 2019; López-Dóriga et al., 2022; Sheng et al., 2016; Weiss et al., 2015). However, to date, the previous literature on micromobility has generally found that the introduction of both shared bikes and e-scooters primarily replaces active and public transportation, with only a limited impact on car users (Felipe-Falgas et al., 2022; Fishman et al., 2013; Reck et al., 2022; Teixeira et al., 2020; Wang et al., 2022). This is especially true for BSS, as documented by studies that were undertaken across various locations, such as Ireland (Murphy & Usher, 2015), Poland (Bieliński et al., 2021), or Australia (Fishman et al., 2014). While research on the effects of e-scooters is still in its early stages, initial findings by Christoforou et al. (2021) in Paris (France) and Bai and Jiao (2020) in Austin (Texas, USA) suggest that e-scooters often replace walking, cycling, or public transportation, which is similar to the conclusions reached in bike-sharing studies.

To date, it is also widely accepted that aspects such as ease of use and comfort (Hardt & Bogenberger, 2019; Plazier et al., 2017; Simsekoglu & Klöckner, 2019; Teixeira et al., 2020), accessibility and flexibility (Dill & Rose, 2012; Eccarius & Lu, 2018; Esztergár-Kiss & Lopez Lizarraga, 2021; Popovich et al., 2014), or time saving (Bateman et al., 2021; Glavic et al., 2021; Kaplan et al., 2018; Krauss et al., 2022) are positively associated with general micromobility use, giving these vehicles a competitive advantage over other traditional modes of transport (Bretones & Marquet, 2022). Contrastingly, safety concerns are often the most noted negative factors associated with micromobility vehicles, hence they present a clear barrier to their adoption (Bretones et al., 2023; Fitt & Curl, 2020; Kopplin et al., 2021; Mitra & Hess, 2021; Sellaouti et al., 2019). Beyond these certainties, there are other functional factors whose effect in micromobility's adoption is, to date, not fully clear. Monetary cost, for instance, varies from being a barrier to adoption to a facilitator of it, depending on the nature of the vehicle (Abouelela et al., 2021;

Bateman et al., 2021; Eccarius & Lu, 2020; Hyvönen et al., 2016; Rejali et al., 2021). Difficulties in finding vehicles when needed or discovering them to be broken, low carrying capacities, and the heaviness of the vehicles themselves are other examples why sharing systems are often seen as impractical and inconvenient micromobility strategies, compared to private micromobility. This is especially true when the vehicles are being used to commute to work, because the factor of time can be particularly relevant. However, when travelling for personal or leisure purposes, these characteristics do not seem to be determinant (Eccarius & Lu, 2020; Sanders et al., 2020). Reliability is also a factor that seems to differ according to the micromobility vehicle in question. According to Krauss et al. (2022) and Patil and Majumdar (2021), unlike users of sharing schemes, micromobility vehicle owners often state the risk of theft (especially when parking in public spaces) and the 'range anxiety' (potential insufficient battery charge) as major concerns. In sum, there are a significant number of functional factors whose association with micromobility depends largely on the type of vehicle (scooter vs. bike), and on the type of mobility operating system (shared vs. private).

#### 4.2.2.2. E-scooters and BSS in the context of a policy-constrained micromobility environment

Cities, globally, started adopting bike-sharing systems (BSS) around the 2010s, through both public and private initiatives (Z. Chen, van Lierop, et al., 2020; Galatoulas et al., 2020; NACTO, 2019). E-scooters were then incorporated, mainly through allowing private initiatives to operate in the city (Brustein, 2018; Marshall, 2018; POLIS, 2019). Because of these chronological differences, both transport managers and policymakers have had to adapt city regulations to the specific needs of each micromobility mode of transport as they were being introduced and becoming more popular. Consequently, regulations for BSS are often not the same as those for e-scooters. Most importantly, the degree of acceptance that cities have had towards publicly operated BSS, has not always been extended to the privately operated scooter-sharing systems (SSS). A number of instances have seen a municipality promote and protect the implementation of BSS, to later oppose or overregulate the deployment of SSS. This is the case for Luxembourg, whose City Council requested free-floating companies to remove e-scooters from the streets in 2019, or Riga, which submitted a proposal to the Latvian parliament to revoke or suspend the license of e-scooter sharing services. More recently, in April 2023, Paris voted to join this group. Through a binding referendum, citizens voted to not extend licenses to operators, and to effectively ban shared e-scooter from public spaces. Beyond European borders, cities as Winston-Salem (North Carolina, US) or Dallas (Texas, US) are just two examples where municipalities have banned the use of SSS due to public safety concerns.

These fragmentations of regulations, for both terms of use and service provision, have relevant implications on how transferrable and replicable results of research conducted in areas with different policy and regulation scenarios are. To date, however, most analyses seem to wrongly assume that the same policies and regulations affect all available micromobility modes equally. In this context, most of the studies have employed datasets of a single micromobility service, and only a few comparative studies of two modes exist (Campbell et al., 2016; Lazarus et al., 2020; Younes et al., 2020). To our knowledge, there is not yet any literature on the usage, competition, and mode choice behaviour between private e-scooters and docked-bike sharing.

The aim of this paper is, therefore, to fill the research gap regarding the lack of understanding on why users prefer private e-scooters over shared bikes, or vice versa. In doing so, this paper also analyses some of the underlying and subjective aspects of micromobility use, such as satisfaction levels or reasons for choosing each individual mode of micromobility. By using the Barcelona case, we are able to locate this analysis in a city with optimal micromobility conditions and two well-established micromobility-operating modes. This enables us to identify the different determinants of modal choice, as well as to assess how likely the users of each mode are to maintain their modal choice in the future. This is particularly important, given the growing prevalence of urban settings, where two of the main micromobility actors differ, not only in the type of vehicle but also, in their operating systems.

### 4.2.3. Methods

#### 4.2.3.1. Study setting

Barcelona is a city with a dense, compact, and mixed-used built environment with about 1.6 million inhabitants (IDESCAT, 2020). With a wide-ranging public transport system, consisting of metro lines, trains, trams, and buses that are distributed throughout the municipality, the city seems to offer the ideal scenario for the implementation of both shared bikes and e-scooters (Marquet & Miralles-Guasch, 2014; McKenzie, 2019). The city operates a successful public bike-sharing system since 2007 under the operator known as *Bicing*, with more than 100,000 users and a fleet of 7,000 vehicles (Soriguera & Jiménez-Meroño, 2020). In 2021, according to the official data, trips using that public docked-bike sharing system grew by 22%, compared to the previous year (Ajuntament de Barcelona, 2021). On the other hand, in 2017 the City Council of Barcelona enacted legislation prohibiting free-floating electric scooter companies (e.g., Lime or Bird) from operating within the city's administrative boundaries (Ajuntament de Barcelona, 2017). Banning shared e-scooter providers from operating within the city-limits was mainly oriented to avoid incidents and dysfunctions that are related to parking malpractice and the occupation of public space. The measure, however, has resulted in a rapid rise in the popularity of privately owned e-scooters, which translated into an increase in e-scooter trips by 179.6% with respect to 2020 (EMEF, 2021). The resulting micromobility scenario is thus one that is also typical of other urban areas, where regulations have made the experience of using and accessing shared e-scooter and bike systems largely different experiences.

#### 4.2.3.2. Data gathering

Data collection was performed by eight street interviewers (Supplementary Table 1) with the help of tablets (Computer-Assisted Personal Interviews, CAPI method), during the second half of September 2020. In order to organise the fieldwork and obtain a sample of users circulating in different parts of the city, recruitment was conducted from 14 survey points covering nine out of ten city districts (Supplementary Table 2). Participants were randomly intercepted on the street or at bike-sharing stations, and they were invited to participate, either before they would start a trip, during an ongoing trip, or after finishing their trip on a private e-scooter or on a docked-shared bicycle. In crowded places, no more than one interview was conducted per group (e.g., per family or group of friends). While this is a non-probabilistic sampling method, it is a cost-effective, faster, and easier way to collect data. To ensure the representativeness of our sample, we undertook a validation exercise using alternative data sources, revealing that the demographic characteristics of our sample, including gender and age, align with those of the broader population who are utilising micromobility within the city. In total, 651 surveys were conducted, over a total period of ten days, with private e-scooter and BSS users above 16 years of age (which is the minimum age allowed to ride an e-scooter and/or short-rent a docked-public bike), who are living and/or working in Barcelona. The survey, which included mainly close-ended questions and lasted approximately 10-15 minutes, provided information about the respondents' sociodemographic profile, current and former travel behaviours, preferences, and motivations (Roig-Costa et al., 2021).

#### 4.2.3.3. Statistical analysis

In order to assess the different aspects of micromobility, a four-step analysis was designed to (1) explore the user profile of each of the two most well-known micromobility alternatives in Barcelona; (2) examine the most prominent socioeconomic and mobile predictors explaining private e-scooter usage as a modal choice over BSS usage; (3) inform the origin of the demand of each of the micromobility modes; and (4) explore the subjective evaluation of private e-scooter and BSS users.

Firstly, to provide an initial description of the user profiles, a semi-descriptive analysis was estimated through bivariate associations using chi-squared ($\chi 2$) tests between each micromobility option, and a set of exploratory variables. The complete set of variables included individual and usage-related factors (Table 1). Individual-related variables were age, gender (*Woman, Man, Non-binary,* or *Prefer not to say*), level of studies (*None, Primary, Secondary,* or *University*), professional status (*Employed, Unemployed, Retired, or Student*), place of residency (*Barcelona* or *Out of Barcelona*), and workplace (*Barcelona* or *Out of Barcelona*). Variables related to the usage were frequency of use (*Daily, Occasionally,* or *Almost Never*) of each of the following means of transport: private e-scooter, BSS, metro, bus, train, and car; and dichotomous variables regarding trip purpose (*Yes* or *No*): commuting, caring, leisure, and accessing public transportation.

Secondly, the analysis of the significant predictors of micromobility modal choice consisted of a multivariate binary logistic regression model, devoted to understanding the choice of private e-scooter over BSS. A binary model was chosen due to the almost non-existent usage relationship between both micromobility modes in Barcelona (see Table 1). The dependent variable in our model was being a user of a private e-scooter (1=Yes and 0=No), and the set of explanatory variables was selected after testing for significance in a bivariate Pearson $\chi^2$ test. The independent variables included demographic factors (Age and Gender), socioeconomic factors (Education level and Professional status), territorial factors (Place of residence and Place of work), and self-reported habitual travel attitudes (Frequency of use and Trip purpose).

Thirdly, to assess the mode replacement dynamics of the different micromobility users the survey included the following counterfactual question: "*Which mode of transport would you have taken if this one (BSS or E-scooter, according to the respondent) had not existed?".* We used a Sankey diagram (SD), which is a visualisation that is used to depict a flow (links) from one set of values to another (nodes). In Fig. 1, the axis on the left side, which indicates the former mode to micromobility, included active modes (*Walking* and *Cycling*), public transport modes (*Subway, Bus* and *Train*), and private modes (*Car* and *Motorcycle*). Respondents were also given the option to answer *"I would have not made this trip".* The axis on the right side shows the current micromobility mode, either BSS or private e-scooter. The volume of the links between nodes represents the importance of a specific modal replacement combination.

Finally, to assess the subjective evaluation of using different micromobility modes in Barcelona, we used descriptive statistics to compare both the level of satisfaction of individuals with their current micromobility mode, and the change in satisfaction level with respect to their former mode of transport. In a similar manner to that used by Paviotti and Vogiatzis (2012), satisfaction with their current micromobility mode was ranked on a scale from 0 to 10, and change in satisfaction level was measured on a scale from *Less satisfactory* to *More satisfactory*. Next, the stated reasons for using either a private e-scooter or BSS were compared. Participants could state up to 3 different reasons in a close-ended question. This type of data has already been used in other transport studies to compare public transport and car users (Van Exel & Rietveld, 2009), or to describe motorcycle behaviour (Marquet & Miralles-Guasch, 2016). To the best of our knowledge, this is the first time that this type of data has been used to describe micromobility behaviour. Analyses were conducted using IBM SPSS v21.

### 4.2.4. Results

#### 4.2.4.1. Exploring micromobility profiles and use: a bivariate analysis

Given the rapid proliferation of micromobility devices in Barcelona, it is important to understand the profile of the user. Men represent almost six out of ten users (59.0%), with the gender imbalance being particularly high for private e-scooter users (63.9% are men). In terms of age group, almost half of the respondents are under 30 years of age (49.3%). Although no significant differences are found between modalities, those respondents over 50 years of age are more likely to be BSS users than private e-scooter users (11.4% compared to 7.7%, respectively). Regarding professional status, the vast majority of respondents are employed (e-scooter 78.2%; BSS 66.5%). However, significant differences are found in the proportion of students using BSS (26.8%) and e-scooters (13.5%). There are also important contrasts with respect to educational level: while 41.4% of e-scooter users have completed their university studies, this percentage rises to 59.7% in the case of BSS users. Finally, significant differences are found in the place of residence and in the place of work. While 78.8% of e-scooter users live within the administrative limits of the city compared to 95.1% in the case of BSS users, 74.8% of e-scooter owners declare working in the city compared to only 56.0% of BSS users.

The rapid introduction of micromobility in cities also requires an understanding of the usage of these new modes of transport. The second part of Table 9 shows the frequency of use of micromobility and traditional modes, together with micromobility trip purposes. Specifically with regard to the frequency of use of micromobility modes, private e-scooter users report a much higher daily use of e-scooter than BSS users report using bike-sharing on a daily basis (85.0% vs. 70.9%, respectively). However, the most noteworthy result is that fact that the vast majority of e-scooter and BSS users state that they never use the other micromobility alternative (95.1% of e-scooter declared never using BSS, while 92.6% of BSS users declared never riding a private e-scooter). Regarding frequency of use of other modes of transport, differences are particularly significant with respect to metro and bus uses, where BSS users show much higher percentages of daily and occasional use than private e-scooter users. Despite some significant differences being found in car use frequency between e-scooter owners and BSS users, those differences are lower. Finally, in terms of trip purposes, the difference between private e-scooter and BSS users with respect to commuting stands out significantly (while 62.3% of the e-scooter respondents cited commuting as a purpose, only 47.7% of BSS users stated the same). Surprisingly, only around 5.5% of users declared using micromobility with the intention of accessing public transportation, with no significant differences between different modes.

Table 9. Individual and usage-related characteristics of the sample.

| | | E-scooter users | | BSS users | |
|---|---|---|---|---|---|
| | | N | % | N | % |
| **Individual-related factors** | | | | | |
| Gender | Woman | 117 | 36.1$^{*}$ | 148 | 45.8$^{**}$ |
| | Man | 207 | 63.9$^{**}$ | 175 | 54.2$^{*}$ |
| Age | <30 yrs | 159 | 48.8 | 162 | 49.8 |
| | 30-49 yrs | 142 | 43.6 | 126 | 38.8 |
| | >50 yrs | 25 | 7.6 | 37 | 11.4 |

| | | | | | |
|---|---|---|---|---|---|
| Professional status | Employed | 255 | 78.2** | 216 | 66.5* |
| | Unemployed | 19 | 5.8 | 17 | 5.2 |
| | Retired | 8 | 2.5 | 5 | 1.5 |
| | Student | 44 | 13.5* | 87 | 26.8** |
| Level of education | None or primary | 31 | 9.5 | 22 | 6.8 |
| | Secondary | 160 | 49.1** | 109 | 33.5* |
| | University | 135 | 41.4* | 194 | 59.7** |
| Place of residency | Barcelona | 257 | 78.8* | 309 | 95.1** |
| | Out of Barcelona | 69 | 21.2** | 16 | 4.9* |
| Workplace | Barcelona | 244 | 74.8** | 182 | 56.0* |
| | Out of Barcelona | 82 | 25.2* | 143 | 44.0** |
| **Usage-related factors** | | | | | |
| Use of private e-scooter | Daily | 277 | 85.0** | 8 | 1.2* |
| | Occasionally | 46 | 14.1** | 16 | 3.7* |
| | Almost never | 3 | 0.9* | 309 | 95.1** |
| Use of BSS | Daily | 9 | 2.8* | 229 | 70.9** |
| | Occasionally | 15 | 4.6* | 79 | 24.5* |
| | Almost never | 302 | 92.6** | 15 | 4.6* |
| Use of metro | Daily | 43 | 13.2* | 80 | 24.6** |
| | Occasionally | 91 | 27.9* | 139 | 42.8** |
| | Almost never | 192 | 58.9** | 106 | 32.6* |
| Use of bus | Daily | 20 | 6.1* | 42 | 13.0** |
| | Occasionally | 63 | 19.3* | 99 | 30.6** |
| | Almost never | 243 | 74.6** | 183 | 56.4* |
| Use of train | Daily | 24 | 7.3** | 12 | 3.7* |
| | Occasionally | 24 | 7.4* | 55 | 16.9** |
| | Almost never | 278 | 85.3** | 258 | 79.4* |
| Use of car | Daily | 25 | 7.7 | 21 | 6.5 |
| | Occasionally | 66 | 20.2** | 42 | 12.9* |

| | | | | | |
|---|---|---|---|---|---|
| | Almost never | 235 | 72.1* | 262 | 80.6** |
| Purpose: Commuting | Yes | 203 | 62.3** | 155 | 47.7* |
| | No | 123 | 37.7* | 170 | 52.3** |
| Purpose: Caring | Yes | 81 | 24.8 | 90 | 27.7 |
| | No | 245 | 75.2 | 235 | 72.3 |
| Purpose: Leisure | Yes | 80 | 24.5 | 99 | 30.5 |
| | No | 246 | 75.5 | 226 | 69.5 |
| Purpose: Accessing PT | Yes | 18 | 5.5 | 19 | 5.8 |
| | No | 308 | 94.5 | 306 | 94.2 |

*= indicates significantly lower values than the overall distribution of the micromobility sample average
**= indicates significantly higher values than the overall distribution of the micromobility sample average
Source= own elaboration

#### 4.2.4.2. Explaining micromobility as a modal choice: a multivariate analysis

In aiming at understanding which factors are behind this growth in micromobility, it is necessary to identify the demographic and usage-related factors that explain the decision to use a private e-scooter. The binary logit model in Table 10 takes into account selected socioeconomic and usage variables, in order to determine the main factors of e-scooter use over docked short-rental bicycle. Results suggest that private e-scooter use is identified with younger men and that it declines with age. The probability of using a private e-scooter is also greater among those respondents who use micromobility for commuting purposes, especially if their place of work falls within the Barcelona City boundaries. On the other hand, results of the regression analysis suggest that the probability of using BSS is greater among those respondents with a university degree. Being a student, living within Barcelona City boundaries, and relying on micromobility for leisure purposes is also associated with a greater probability of using BSS versus using a private e-scooter. In addition, using the metro occasionally or on a daily basis, and the train in an occasional manner, is also associated with a higher probability of using BSS as a micromobility mode over a private e-scooter.

Table 10. Binary logit model of the probability of using a private e-scooter over using BSS in Barcelona.

| | | B | S.E. | Wald | df | Sig. | Exp(B) | 95% C.I. for EXP(B) | |
|---|---|---|---|---|---|---|---|---|---|
| Variables | | | | | | | | Inferior | Superior |
| Constant | | 2.586 | 0.534 | 23.478 | 1 | 0 | 13.276 | | |
| Age | | -0.035 | 0.01 | 11.924 | 1 | 0 | 0.966 | 0.947 | 0.985 |
| Gender | Woman | -0.66 | 0.195 | 11.479 | 1 | 0.001 | 0.517 | 0.353 | 0.757 |
| Professional status | Employed | | | 27.727 | 3 | 0 | | | |
| | Unemployed | 0.956 | 0.49 | 3.806 | 1 | 0.051 | 2.602 | 0.996 | 6.801 |
| | Retired | 1.178 | 0.723 | 2.651 | 1 | 0.103 | 3.248 | 0.787 | 13.408 |
| | Student | -1.242 | 0.38 | 10.697 | 1 | 0.001 | 0.289 | 0.137 | 0.608 |
| Education | None or primary | | | 29.9 | 2 | 0 | | | |
| | Secondary | 0.196 | 0.361 | 0.296 | 1 | 0.587 | 1.217 | 0.599 | 2.471 |
| | University | -0.993 | 0.372 | 7.136 | 1 | 0.008 | 0.37 | 0.179 | 0.768 |
| Place of residency | Barcelona | -1.991 | 0.368 | 29.254 | 1 | 0 | 7.32 | 3.558 | 15.057 |
| Workplace | Barcelona | 0.963 | 0.303 | 10.114 | 1 | 0.001 | 0.382 | 0.211 | 0.691 |
| Trip purpose | Commuting | 0.592 | 0.208 | 8.107 | 1 | 0.004 | 1.808 | 1.203 | 2.718 |
| Trip purpose | Leisure | -0.549 | 0.222 | 6.097 | 1 | 0.014 | 0.577 | 0.373 | 0.893 |
| Use of metro | Never | | | 30.729 | 2 | 0 | | | |
| | Sometimes | -0.993 | 0.208 | 22.865 | 1 | 0 | 0.37 | 0.247 | 0.557 |
| | Often | -1.201 | 0.278 | 18.683 | 1 | 0 | 0.301 | 0.174 | 0.519 |
| Use of train | Never | | | 8.544 | 2 | 0.014 | | | |
| | Sometimes | -0.957 | 0.329 | 8.441 | 1 | 0.004 | 0.384 | 0.201 | 0.732 |
| | Often | -0.054 | 0.454 | 0.014 | 1 | 0.906 | 0.948 | 0.389 | 2.307 |

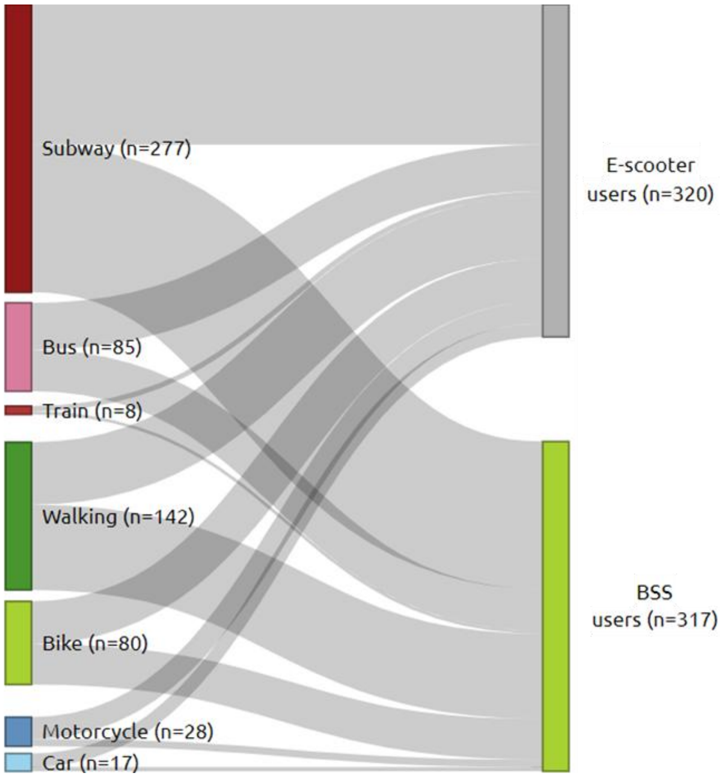
Notes for the model: Rho-Square (Nagelkerke)=0.353; -2log likelihood=696.782; Pseudo $R^2$ (Cox and Snell)=0.265
Source: own elaboration

#### 4.2.4.3. Mode replacement dynamics of micromobility

A particularly relevant issue for the study of micromobility in cities is the modal origin of new users. In order to understand where the micromobility demand comes from, Figure 11 shows the mode of transportation which both private e-scooter users and BSS users used prior to using their micromobility device. On average, 56.8% of the current micromobility users switched from public modes of transport and 34.1% switched from active modes of transport, whereas only 6.91% switched from a private mode of transport.

By type of vehicle, the largest mode transfers are found between the metro and BSS (43.7%), and between the metro and private e-scooter (41.4%). Walking is the second highest mode of transport to have been abandoned in favour of either BSS (25.2%) or private e-scooter (18.6%). Regarding private motorised modes of transportation, there is a slight difference between private e-scooter users and BSS users: while more than 10% of private e-scooter owners come from private motorized modes, only 3.4% of BSS users were previously driving a private motorised vehicle.

Figure 11. E-scooter and BSS modal replacement scheme




Source: own elaboration

#### 4.2.4.4. Subjective evaluation of micromobility

Table 11 shows, on a scale from one to ten, how owners of e-scooters and users of BSS evaluate their satisfaction with their micromobility mode. Private e-scooter users evaluate their mode of transport the highest, the average mark being $\overline{X}$=8.94, in comparison with $\overline{X}$=7.51 of BSS users. On average, e-scooter users are 1.19 times more satisfied than BSS users. By transport mode, former public transport users show the highest differences (1.22) between e-scooter and BSS. Only among users switching from private modes, do e-scooter users show a lower average level of satisfaction than their BSS counterparts. In fact, across all current e-scooter users, former users of private modes show the lowest satisfaction mark. At the same time, those respondents showing the highest satisfaction level across all BSS users are precisely the ones switching from private modes.

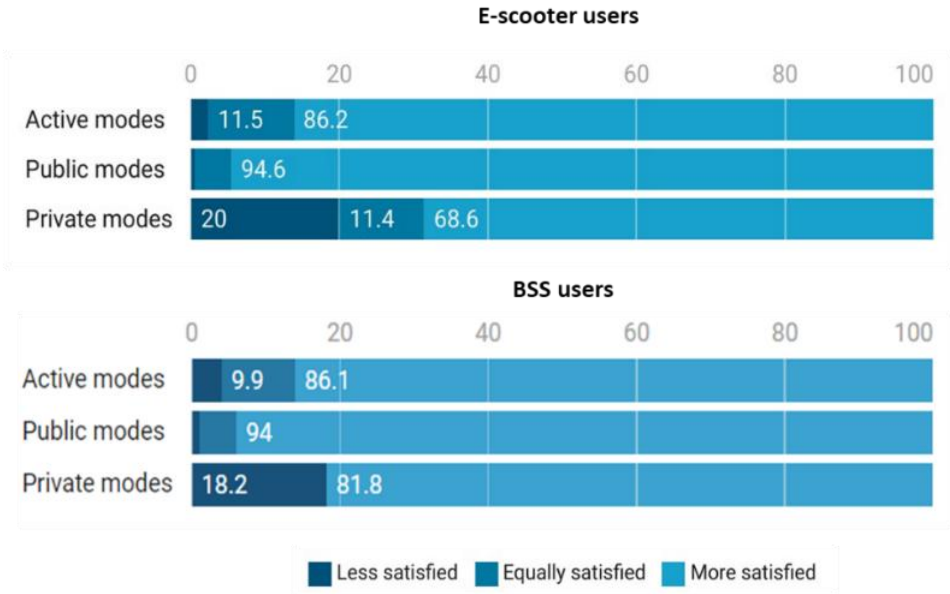
Table 11. Subjective assessment of satisfaction on private e-scooters and BSS.

| Former means of transport | E-scooter users (out of 10) | BSS users (out of 10) | Difference E-scooter/BSS |
|---|---|---|---|
| All modes | 8.94 | 7.51 | 1.19 |
| Active modes | 8.88 | 7.53 | 1.18 |
| Public modes | 9.06 | 7.44 | 1.22 |
| Private modes | 8.51 | 8.73 | 0.97 |

Source: own elaboration

In addition, the satisfaction levels of private e-scooter users and BSS users transitioning to micromobility were assessed using a scale ranging from *Less satisfactory* to *More satisfactory* (Figure 12). Results reveal an overall positive trend in micromobility user satisfaction. However, a substantial difference arises between those respondents coming from active and public modes of transport, and other respondents coming from private motorised modes. While almost no former public transport users report feeling less satisfied with the new micromobility mode of transport, a considerable percentage of former motorised vehicle users report being less satisfied with the change to micromobility, especially across e-scooter users. Former active modes users appear to be more satisfied with their new mode of transportation. Nevertheless, although the percentage of more satisfied users is significant, the share of former active modes users declaring being equally or less satisfied with the change to micromobility is not insignificant.

Figure 12. Change in satisfaction versus former mode of transport




Source: own elaboration

To understand why e-scooter users are more satisfied than BSS users, it is important to analyse the reasons behind their choosing to use the e-scooter. Comparing answers from e-scooter owners with those of BSS users also helps to understand the hidden rationale behind each mode of transport choice. As shown in Table 12, in general, both e-scooter owners and BSS users point to similar principal reasons when asked about the main reasons for using micromobility. Of all the BSS users, 60.3% pointed to *"Ease, speed, and agility"* as the main reason, 17.2% to *"Save money"*, and 14.2% to *"Good for the environment"*. E-scooter owners agreed in both the ease of use and speed issue (62.6%), and also with respect to the monetary cost (18.7%), but the environment (6.1%) was clearly not a factor for them.

However, in using a cross-mode strategy for analysis, it is when crossing the current micromobility mode with the replaced transport mode when main reasons for micromobility adoption between e-scooter owners and BSS users diverge significantly. Among former users of private modes, current private e-scooter users are 3.82 times more likely to justify their use of the e-scooter by the ease, speed, and agility that it provides than their BSS counterparts. Former public and active modes users currently using a private e-scooter were 3.1 and 2.66 times, respectively, more likely to rationalise their choice due to personal pleasure (i.e., "having fun"). The COVID-19 pandemic was also an important factor for e-scooter owners compared to BSS users, especially for former active and public mode users. In contrast, among current BSS users "Saving money" and "Good for the environment", respectively, were cited more by former users of private modes and former active and public mode of transport users. In sum, private e-scooter use is basically characterised by an operational factor such as ease of use, speed, and agility, especially in the case of former private modes users, and by an extra subjective factor, such as personal pleasure, for former active and public modes.

Table 12. Reasons for changing to private e-scooter and BSS, according to former transport mode.

| | E-scooter users | | | BSS users | | | Odds Ratio (E-scooter) | | |
|---|---|---|---|---|---|---|---|---|---|
| | Active modes | Public modes | Private modes | Active modes | Public modes | Private modes | Active modes | Public modes | Private modes |
| Save money | 15.9% | 21.6% | 8.6% | 16.8% | 20.0% | 18.2% | 0.93 | 1.1 | 0.42 |
| Ease, speed, and agility | 70.5% | 57.3% | 68.6% | 68.3% | 55.1% | 36.4% | 1.11 | 1.09 | 3.82 |
| Good for the environment | 4.5% | 6.5% | 11.4% | 10.9% | 15.1% | 18.2% | 0.39 | 0.39 | 0.58 |
| Personal pleasure | 4.5% | 4.9% | 5.7% | 2.0% | 1.6% | 9.1% | 2.36 | 3.1 | 0.61 |
| COVID-19 | 3.4% | 9.7% | 5.7% | 2.0% | 6.5% | 9.1% | 1.75 | 1.55 | 0.61 |
| Physical activity | 1.1% | 0.0% | 0.0% | 0.0% | 1.6% | 9.1% | - | 0 | 0 |
| Total | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | 100.0% | | | |

Source: own elaboration

### 4.2.5. Discussion

The unprecedented boom in micromobility devices on the streets of Barcelona has political, technical, and contextual explanations. On the one hand, the Barcelona City Council's decision in 2007 to promote a short-term bicycle rental system, created the possibility for many non-bicycle owners to use a bicycle for intra-city short-distance travelling. The introduction of an electrified fleet, later allowed for the expansion of the system to parts of the city that were traditionally considered unsuitable for bicycle use, thus reinforcing its popularity (Codina et al., 2022). With respect to e-scooters, the 2017 City Council decree to not allow private operators of shared e-scooters within the city limits completely conditioned the landscape of the sharing services operating within the city and left an unmet demand that swiftly led to the proliferation of privately owned e-scooters. Other contextual factors, such as the COVID-19 pandemic, accelerated micromobility's deployment, leading to an increase of transfers from traditional modes of transport (mainly public transport) towards modes such as BSS or private e-scooter. These modes were perceived as safer alternatives, capturing first-time users who have most likely consolidated their use over time (A. Li et al., 2021).

In absolute terms, our results confirm that micromobility vehicles in Barcelona are predominantly used by young, urban, and employed men. The masculinisation in the use of micromobility vehicles is a phenomenon that is common to many other cities, such as New York (United States) (Reilly et al., 2020a), Gdansk (Poland) (Bielinski & Wazna, 2020), and Passo Fundo (Brazil) (Sardi et al., 2019). A plausible explanation for this gender gap is that women might be more risk averse and sensitive to safety issues (Sanders et al., 2020). In cities like Barcelona, where the bike lane network is still highly fragmented, the feeling of insecurity, compared to other modes of transport, is compounded for women. Our models demonstrate that this relationship between women and risk is especially accentuated in the case of private e-scooters. According to both Arellano and Fang (2019) and (Cubells et al., 2023a), e-scooter users who are men drive faster than their women counterparts, with this difference being particularly pronounced in pedestrian areas. In fact, a recent study set in Barcelona found that risk-taking and fast-riding practices can discourage other potential users from sharing the same infrastructure, thus hindering the potential uptake of micromobility modes, and also damaging the prospects for more sustainable mobility (Cubells et al., 2023b). Considering that in Barcelona the majority of pedestrians are women (Maciejewska et al., 2019; Marquet & Miralles-Guasch, 2015), and the majority of e-scooter users are men, the adoption of electrified micromobility may be changing the use and perception of safety in public space, and challenging established patterns in its use, thus creating conflicts that especially affect the most vulnerable social groups (Fitt and Curl, 2020).

Our results also demonstrate the existence of a true generational gap in the use of micromobility vehicles. Due to issues that are linked to health and physical conditions, such as posture problems or loss of balance (Johnson & Rose, 2015), older adults have been found to have a greater aversion to the adoption of micromobility vehicles, and a lower predisposition to the use of technologies that are associated with them (Campisi et al., 2020). The existence of such a pronounced gap calls into question issues about the actual accessibility of these vehicles, and their potential to contribute to transportation justice, especially in the case of the e-scooter (Bielinski & Wazna, 2020; Spinney, 2020).

However, whereas sociodemographic factors, such as gender and age, can explain the growing trend of micromobility as a whole, our results indicate that the decision to actually use private e-scooters over BSS in Barcelona appears to depend more on socioeconomic factors. In contrast to the previous literature, Barcelona shows a strong negative relationship between e-scooter use and educational level, which might be explained in part by the existing ban on shared e-scooters. Unlike in other cities, the use of e-scooters in Barcelona is not subject to owning a smartphone, downloading an app, or paying through a credit/debit card. The user does not require a specific knowledge on vehicle location and how to unlock the vehicle, or any expertise regarding parking prohibition and regulation. Notably, unlike the prevailing trend observed in most Western cities, e-scooter usage is not contingent upon a pay-per-use model, a factor which is commonly found to act as access barriers for low-income groups. The political decision to ban free-floating e-scooters left an unmet demand that swiftly sought comfort in private e-scooters. This sudden demand for privately owned e-scooters drove down their selling prices, making it an inexpensive personal mobility alternative that requires only a modest initial investment (around 200 euro), what has led to an even faster proliferation of privately owned e-scooters. The removal of the technological, economic, and information barriers has especially accelerated the introduction of the private e-scooter among socioeconomically disadvantaged populations, offering the dynamism and convenience of micromobility services, without having to participate in electronic payments, app registrations, or formal registration.

This dynamic might be even stronger, given the fact that other shared micromobility services such as public BSS or shared mopeds, that are indeed allowed to effectively operate in the city, have spatial biases and offer unequal service to all city areas (Bach et al., 2023a). In practice, what this means is that these services are often limited to operate within the municipal limits, and are specifically concentrated in central areas, where people with higher socio-economic status tend to live, resulting in a lower supply in lower income neighbourhoods. These service-coverage issues have been found in other European cities (Dill et al., 2019a), but in the case of Barcelona they contribute to explain the popularity of private e-scooters, which allow for crossing municipal boundaries, metropolitan multimodality and better convenience on planning complex routes. The combination of banning shared e-scooter services to operate within city boundaries, and the fact that other micromobility shared services concentrate their services in central areas of the city, might have led a substantial number of low-income people in the city to adopt privately owned e-scooters, now seen as a highly convenient everyday mobility alternative.

At the same time, our model confirms that micromobility use in Barcelona is strongly linked with trip purpose. On the one side, e-scooter use in our study appears to be strongly associated with occupational mobility. This finding contradicts previous studies on the subject (S. Bai et al., 2021; H. Li et al., 2022), where e-scooter trip purposes are more likely to relate to leisure and recreation activities. In contrast, our results show that BSS use is more associated with leisure trips. These differences across distinct operating systems might be related with time management issues. For work-related trips, the variability and uncertainty in travelling can create anxiety around the fear of being late (Costa et al., 1988; Delclòs-Alió & Miralles-Guasch, 2017). Since in some parts of the city the demand for shared bikes tends to be higher than the supply, users do not have the total certainty of being able to access a vehicle when needed, making travel time unpredictable. This would explain why a large proportion of BSS users rely on other modes of transport for their commute to work. The private nature of the e-scooter eliminates the uncertainty that is derived from the possible lack of supply (De Witte et al., 2013), which would explain its greater use for work purposes. This is reinforced by topography, the Mediterranean climate (i.e., sub-tropical coastal), and the degree of physical effort that is required during commuting, connected with the fact that most workplaces in the city lack shower facilities, dryers, or lockers. This combination seems to discourage the use of BSS in work-related trips, and increases the use of private e-scooters, which require less effort (Hipp et al., 2017; R. Zhu et al., 2020). In contrast, for trips that are related to personal reasons, which tend to be associated with greater spatial complexity, carrying around a private e-scooter can be seen as a burden (Scheiner & Holz-Rau, 2017). In addition, mobility for personal purposes is often associated with a greater use of proximity (Marquet & Miralles-Guasch, 2014), thus allowing for more relaxed time management, which is reflected in a greater use of BSS.

On a replacement analysis level, our results indicate that in Barcelona most of the new users of micromobility are former users of public and active modes of transport. These findings are consistent with the previous literature (Bieliński et al., 2021; Murphy & Usher, 2015; Teixeira et al., 2020) and contrast with the belief that micromobility emergence can help us decarbonise mobility and lower car-dependency in urban areas (Feng et al., 2020; Hardt & Bogenberger, 2019; The Nunatak Group, 2019). This is especially true in European urban environments (Wang et al., 2022), where cars represent lower percentages in the modal split due to historical built environment conditions. From an environmental perspective, our findings suggest that although micromobility adoption might bring a slight reduction in traffic congestion, air and noise pollution, and energy consumption (DeMaio, 2009; Shaheen et al., 2011), to date, that potential is low (Felipe-Falgas et al., 2022). On the other hand, this modal shift also has implications in terms of health, especially in relation to the use of electric modes of transport (Milakis et al., 2020). Although it is premature to state what consequences it may have (Ognissanto et al., 2018), it does appear that e-scooter use decreases physical activity more than bike sharing. At the same time, in terms of the occupation of public space, the increase in the number of micromobility users places even more pressure on the limited resource of public space, especially in a context of a compact and highly dense city such as Barcelona.

Linked with the above, but focusing on the subjective dimension of the analysis, it is noteworthy how former users of public transport modes are much more satisfied with the change to micromobility than former private transport modes users. According to De Vos and Witlox (2017), the choice of a travel mode will probably be affected by satisfaction with previous trips using that particular mode. This link between satisfaction and behaviour also seems to be confirmed by studies in the domain of marketing and customer behaviour (Olsen, 2007). These studies indicate that customer satisfaction strengthens customer loyalty, meaning that satisfied customers are more likely to continue using that service. Considering these theories, it is worrying that the most satisfied users are those replacing public transport modes rather than private transport modes, especially in the case of the private e-scooter. In addition, our results show a strong inverse relationship between the use of metro and train and the probability of using a private e-scooter, suggesting a clear disconnection of e-scooter users from public transport modes, unlike users of BSS, who show wider modal mixes. This phenomenon is especially worrisome considering the traditional importance of public transport as the backbone of metropolitan everyday mobility, and it will have consequences for public space occupation and availability.

The fact that the drivers of micromobility adoption are so differentiated from the drivers of traditional modes, shows that micromobility use cannot be compared or analysed using the same standards as other modes of transport. In addition, nuances between e-scooters and BSS also exist, especially when they do not share the same operating system, and thus proper attention should be given to each of them as a unique form of transport, answering singular and specific user needs. Differences in factors for the adoption of the e-scooter and BSS are even more relevant when considering the modal switch and former modes of transport. For instance, former car drivers who have now become private e-scooter users tend to place more emphasis on ease of use and agility. On the other hand, for users switching from public modes of transport, private e-scooters are more attractive than BSS due to subjective factors such as enjoyment and thrill seeking. Driving in a dense and compact city such as Barcelona seems to provide a playful trip experience for e-scooter riders who are switching from these specific transport modes, in contrast with the more functional trip experience that BSS appear to provide (Christoforou et al., 2021; Glenn et al., 2020).

### 4.2.6. Conclusions

Our study has analysed fundamental differences that could explain the preferred adoption of privately-owned e-scooters over public BSS in Barcelona. The study has hypothesised that policy restrictions that are present in Barcelona might explain some of the internal differences, especially at the socioeconomic level. We argue that the policy of banning free-floating e-scooter services has resulted in a greater part of the lower-income population choosing to own e-scooters. Paradoxically, a decision that was intended to promote a more democratic and accessible public space, has skewed the relative cost-benefit analysis of different micromobility transport options, and has led to an increase in the desirability of privately-owned e-scooters, particularly among individuals from economically disadvantaged backgrounds. Our results have also shown that micromobility in Barcelona presents features that are similar to those in other urban settings, as young and employed men, on average, use micromobility modes of transport the most. Place of residency, place of work, trip purpose, and frequency of use of public transport, all also have a strong bearing on the likelihood of an individual choosing to use a private e-scooter over the BSS. Barcelona's present circumstances, which were once considered atypical, are gradually becoming commonplace in numerous capital cities across the globe. Hence, we argue that the findings of this study possess a representative nature and merit particular attention within urban contexts that are characterised by comparable legal frameworks, both at the present time and in the foreseeable future.

A worrisome finding is that micromobility modes in Barcelona are not absorbing car users, but rather public transport and former users of active modes of transport, such as walking. This phenomenon calls into question the potential of micromobility as a tool to fight the climate emergency, and it also has implications in terms of health and public space. Finally, our study found that satisfaction indexes differ across replaced modes. These results might mean that the few former private transport users which micromobility has managed to attract might not be as loyal as transport users coming from active and public modes, which would further question the potential of micromobility as a tool with which to combat the hegemony of private motorised vehicles.

This study is not without limitations. Firstly, the utilisation of a non-probabilistic sampling technique, followed by a random intercept mechanism, limits our study's ability to extrapolate our findings to the entire City of Barcelona. In addition, the present authors are aware that, due to the fact that data collection took place when the global traffic situation was of a particularly special nature during the Covid-19 pandemic, results should be viewed carefully. However, although it is true that Barcelona, like many other cities in Europe, implemented specific measures towards the promotion of micromobility (e.g., pop-up bike lanes) to counterbalance the avoidance of transit use, it is also true that most of those interventions have been maintained over time and have even gone further, which may alleviate the limitation.

In conclusion, these findings highlight the fact that micromobility modes rarely operate under a homogenic regulative structure and policy framework in any city. Therefore, it is crucial to understand how specific policy decisions may affect the adoption of e-scooters or shared bikes differently. Policymakers must take into account the socioeconomic consequences of micromobility policies, as well as their effectiveness in addressing the climate emergency, reducing car dependency, and their impact on public space utilisation.

# 5. Micromobility at a street level: situated practices and everyday adaptations

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

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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

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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.

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### 5.1.1. 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 & 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, Van Lierop, et al., 2020).

It is widely recognized that their establishment in urban 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 & 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., 2024b), 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 & Cai, 2019; J. Zhang et al., 2016), often serving as first- and last-mile solutions that complement public transportation (D. 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, Van Lierop, 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.

### 5.1.2. 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 & Harms, 2019; Y. Yang et al., 2019), street connectivity (Y. Sun et al., 2017), and land use mix diversity (Cervero et al., 2009; Y. 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 (Y. Sun et al., 2017), which leads to reductions in both cycling frequency and volume (Pucher & Buehler, 2016). Careless and reckless driving behaviour further diminishes cyclists' sense of safety significantly (Fruhen & 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 & 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 & Dill, 2016; Fraser & 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 & 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 &

Nieland, 2021; Z. Lin & Fan, 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 & 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 & Jarvis, 2021; Van Cauwenberg et al., 2018) and gender (Cubells et al., 2023b; Hardinghaus & Weschke, 2022a), 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 & O'Holleran, 2014; Mayers & Glover, 2021) or similar aversion to spots with a high number of intersections (E. Chen & Ye, 2021; Cubells et al., 2023a; Guo & He, 2020), exposure to some other elements affects regular cyclists and bike-sharing users differently. Studies in China (E. Chen & 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 & 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 & 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 & 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 & Yang, 2011), with optimal station spacing typically ranging between 250-300 metres, a distance believed to maximize accessibility for users while minimizing operational and maintenance costs (García-Palomares et al., 2012a). High-density areas and city centres are often prioritised, with stations placed near transit hubs and in proximity to residential and commercial areas (Gehrke & 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 & 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 & 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 & 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 & 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.

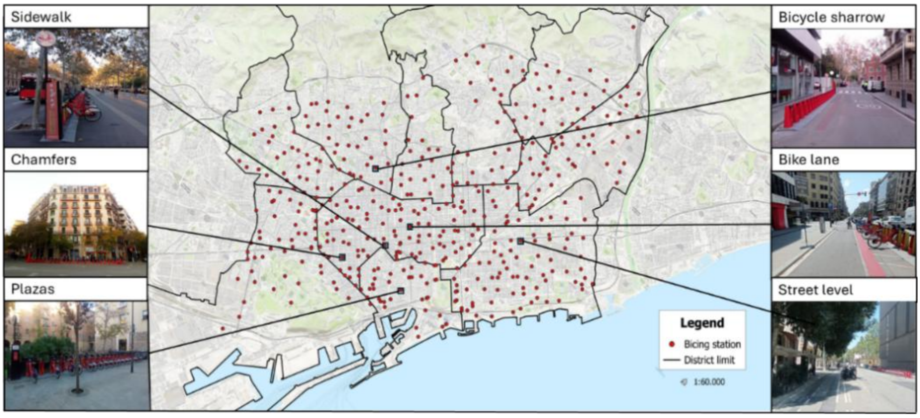
In summary, quite a few studies have focused specifically on the relationship between physical external factors and bike-sharing usage. However, most of these studies have used a variety of quantitative methods, such as surveys (Campbell et al., 2016), geographic information systems (Kabak et al., 2018) 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 & 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 & 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).

### 5.1.3. Method

#### 5.1.3.1. 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 (Figure 13) and a fleet of 7,108 bicycles, of which 4,000 are electric (Soriguera & 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 minutes. Trips exceeding 30 minutes incur an additional fee of €0.70 for each extra 30 minutes. For electric bikes, an extra €0.35 is charged per trip, and each additional 30 minutes 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.

Figure 13. Public docked-shared bicycle (*Bicing)* stations and station typologies in Barcelona




Source: own elaboration

### 5.1.3.2. 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.

#### 5.1.3.3. 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 & Arsal (2017), participants were encouraged to share their thoughts and emotions from the beginning to the end of the trip. Recognising 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, Map 4 displays BSS01 tracked trip. Additional specific trips for all participants in our study can be found in the Supplementary Materials.

Map 4. Participant BSS01 trip


Source: own elaboration

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 minutes 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 13). During this phase of the study, the research team accumulated a total of almost eight hours of video and more than 14 hours of interviews.

Table 13. Participants' characteristics and BSS travel related behaviour

| Participant Code | Gender | Age | Bicycle-sharing typology[a] | BSS frequency of use[b] | Bicycle ownership |
|---|---|---|---|---|---|
| BSS01 | Man | 30 | Electric | High | No |
| BSS02 | Man | 31 | Electric | Medium | No |
| BSS03 | Man | 39 | Conventional | High | No |
| BSS04 | Man | 27 | Conventional | Medium | Yes |
| BSS05 | Woman | 42 | Conventional | Medium | No |
| BSS06 | Man | 60 | Electric | High | No |
| BSS07 | Man | 37 | Conventional | Medium | Yes |
| BSS08 | Woman | 45 | Conventional | High | Yes |
| BSS09 | Woman | 40 | Conventional | High | No |
| BSS10 | Woman | 53 | Conventional | Medium | No |
| BSS11 | Woman | 31 | Conventional | Medium | No |
| BSS12 | Woman | 24 | Conventional | High | No |
| BSS13 | Man | 31 | Conventional | Low | No |
| BSS14 | Man | 23 | Conventional | Medium | Yes |
| BSS15 | Man | 26 | Electric | Medium | No |
| BSS16 | Man | 27 | Conventional | Medium | Yes |
| BSS17 | 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.
Source: own elaboration

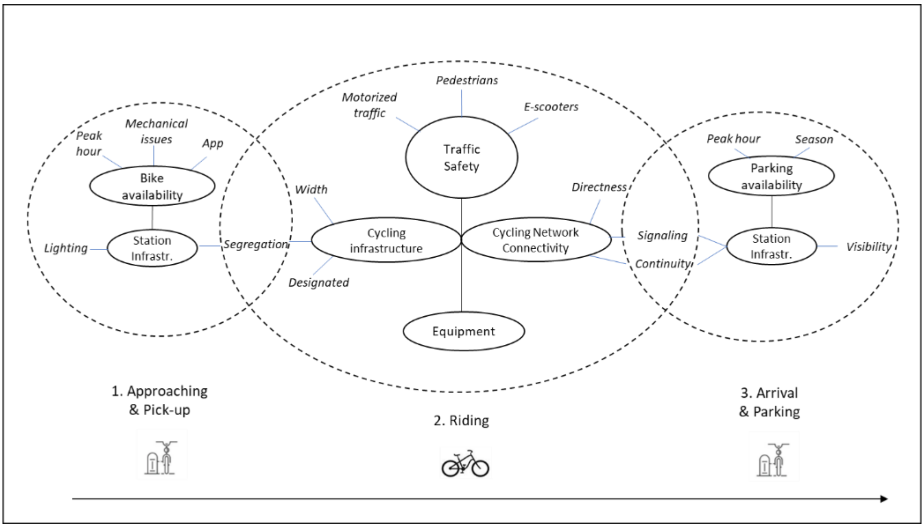
#### 5.1.3.4. Analyses

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.

### 5.1.4. 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 (Figure 14). 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.

Figure 14. External aspects influencing the experience of bike-sharing. Model derived from the inductive analysis.




Source: own elaboration

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.

*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."* (BSS02). 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.

Figure 15. Example of a participant encountering bicycle unavailability at a station located near a major mobility hub

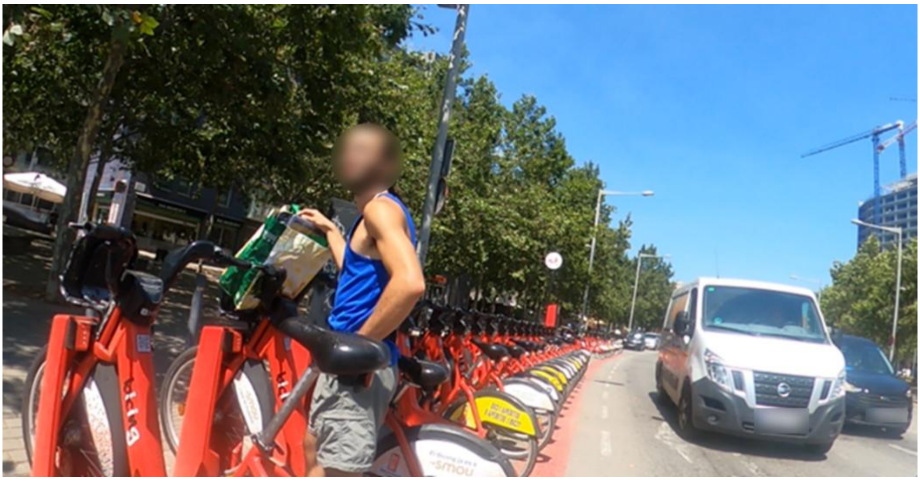
Source: author's own

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."* (BSS02). 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.

*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."* (BSS08). 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.

Figure 16. Example of a docking station perceived as unsafe



Source: author's own

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 (Figure 14). 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.

*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 BSS16 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"* (BSS06). 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.

Figure 17. 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 BSS15, 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"* (BSS08). 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.

*Cycling infrastructure*

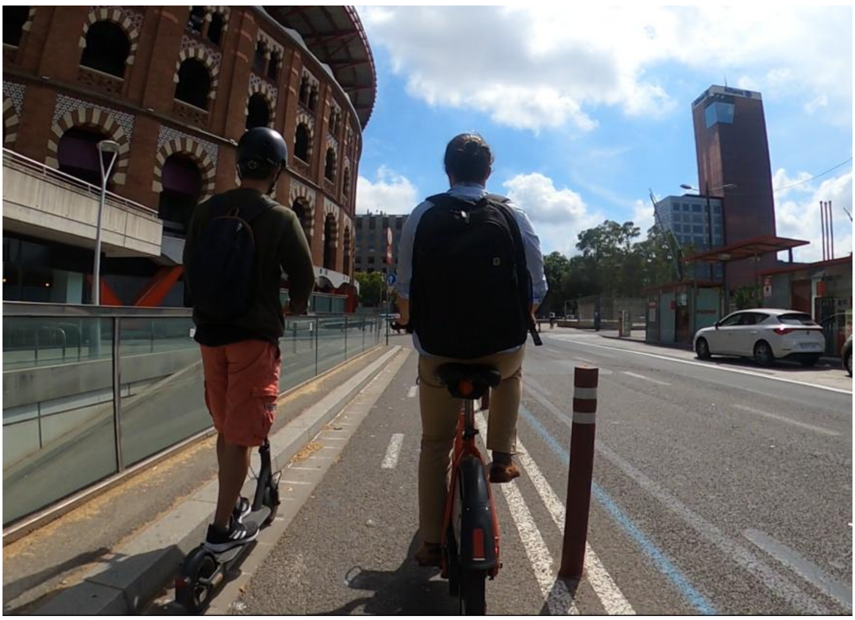
As a result, almost all participants expressed a clear preference for cycling within designated spaces over sharing space with other users. The heightened perceived risk and aversion associated with riding alongside high-speed traffic -particularly when private motorised vehicles, such as motorbikes, 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 BSS15, 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.

Figure 18. 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."* (BSS08). 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.

Figure 19. Example of narrow and bidirectional bike lane where speed and space conflicts with other bike lane actors become evident



Source: author's own

*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 BSS04 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.

Figure 20. 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 BSS07, BSS10 and BSS17, who did not regularly incorporate cycling into their mobility strategy, confessed only using bike-sharing when properly knowing the way. As distilled from BSS10 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"*.

*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, BSS06 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.*" (BSS10). The physical demand of riding a shared bike was also mentioned by some participants owning a private bicycle. BSS14, 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, BSS08 admitted modifying 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. BSS01, 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.

Figure 21. Participant adjusting the bike seat during the ride

Source: author's own

<u>Arrival at destination and parking</u>

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.

*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 & 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 BSS08. 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 BSS08'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"*.

*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 BSS06 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.

Figure 22. 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

### 5.1.5. 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.

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 & 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 (L. 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 & Falcão, 2020; T. Johnson & 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, 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, 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 & Glover, 2021).

## 5.2. Affective geographies of e-scooter travel: Infrastructure, emotions, and adaptive strategies.

**Abstract** Despite their popularity, only limited attention has been given to understanding what captivates e-scooter riders and sustains their interest in the device. While surveys consistently rank e-scooters as a highly satisfying transport mode, such evaluations often reduce complex experiences to a single numeric score, leaving much unexplored. Using a videorecorded ride-along methodology, this study examines how infrastructure and spatial configurations influence the affective experiences of twelve e-scooter riders in Barcelona. Our observations reveal that trips encompass a wide range of emotional registers, from positive activation to negative deactivation emotions, often contingent on the quality of the infrastructure. Furthermore, by combining observational material with participants' interview narratives, we show that the intrinsic characteristics of these devices—lightness, manoeuvrability, and quiet operation—play a key role in how participants define relationships with infrastructure and the situations encountered. By uncovering the interplay between cycling infrastructure, emotions and adaptive strategies, this paper shed light on the processes underpinning e-scooter satisfaction and underscores the importance of integrating affective dimensions into urban design.

*Keywords*: E-scooter; Ride-along; Emotions; Infrastructure; Adaptive strategies; Satisfaction

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### 5.2.1. Introduction

Introduced in 2017 and consolidated in the aftermath of the pandemic, the popularization of electric scooters (e-scooters) in cities has expanded the travel possibilities available to urban dwellers (Nello-Deakin et al., 2024; S. Sun & Ertz, 2022). At the same time, however, their deployment has changed the dynamics of urban mobility, introducing new levels of complexity, and posing new challenges at a city level. Especially in dense and compact urban environments, where space is a particularly finite resource, the rising number of e-scooters in circulation has caused the domains reserved for conventional transport to become blurred (Gibson et al., 2022), sparking controversy and debate among private motorized vehicle drivers, pedestrians and even cyclists. E-scooter riders often struggle to find their place, leading to disputes over urban territories which could generate undesired feelings and psychological, physical, and emotional distress to both riders and other street users. The rapid expansion of their use, coupled with the absence of planning strategies for their integration into mobility and urban planning, have led to a disconnect between policy and practice, causing discomfort both for e-scooter riders and other users of the urban space (Anderson-Hall et al., 2019; Ma et al., 2021; Zou et al., 2024). In response to these tensions, this paper argues that promoting inclusive, sustainable, and emotionally attuned forms of mobility requires greater attention to the subjective experiences of micromobility users, particularly in how they relate to infrastructure design and regulatory frameworks.

To date, micromobility research has acknowledged that e-scooter travel behaviour is influenced by environmental factors (S. Bai & Jiao, 2020; Caspi et al., 2020), and that riding experiences may potentially be conditioned by personal preferences and fears (Hardinghaus & Weschke, 2022b). Additionally, previous studies have demonstrated that the use of novel innovations or products, such as e-scooters, initially elicits higher positive emotions, and that these emotions often diminish over time (Flores & Jansson, 2022). Although recent developments in emotional, affective, and sensorial geographies emphasize the importance of attending to emotions as critical components in mobility research and policy design (O. B. Jensen, 2010; Shaker & Ahmadi, 2022; Tironi & Palacios, 2016), the emotional dimension of e-scooter use, and the ways in which these emotions are shaped by the material, spatial and regulatory configurations of infrastructure, remains largely underexplored. These configurations include elements such as cycle lanes, sidewalks, traffic signals, surface quality, and path continuity, all of which that condition how riders navigate, interpret, and emotionally engage with urban environments.

In fact, despite their growing popularity and wide adoption, e-scooters are often evaluated through general satisfaction surveys that reduce complex, context-dependent experiences to a single score, typically on a scale from 1 to 10 (EMEF, 2023). While these instruments consistently position e-scooters as one of the most satisfying transport modes (Askari et al., 2024; Nikiforiadis et al., 2024), they tend to offer a static and decontextualised view of satisfaction, overlooking its dynamic nature. In particular, such measures fail to capture how satisfaction is shaped by the interaction between bodily sensations, infrastructural affordances, and the everyday rhythms of urban space. This simplification leaves key affective and experiential dimensions unexplored, especially when compared to other micromobility modes that have received greater qualitative attention. As previous researchers have already done in other fields (Bondi, 2005; Roy et al., 2024), there is a need to incorporate affective and emotional geographies that focus on e-scooter riders' experiences of place and space (Glenn et al., 2020; Milakis et al., 2020), closing the knowledge gap regarding the link between the urban infrastructure and the affective dimension of travel.

Drawing on insights from emotional and affective geographies, we conceptualise the built environment as an emotional infrastructure itself, one that modulates how individuals experience, interpret and respond to disruptions or affordances in space. Rather than isolating infrastructure, behaviour and emotions as separate analytical layers, this paper foregrounds their co-constitution: how spatial configurations condition embodied responses, and how these responses, in turn, inform adaptive travel strategies and affective states. By examining specific e-scooter trips through the lens of affective atmospheres and the work of emotions (Quéré, 2012), we explore how users' experiences influence their mobility practices and their relational engagement with infrastructure. These affective atmospheres are not static but constantly redefined by individuals, shaped by their available resources, perceptions, and interactions with the urban environment. This paper aims to contribute to bridging the identified knowledge gap by advancing a situated understanding of how infrastructural and spatial design conditions influence both the emotional and behavioural dimensions of travel. In doing so, we move beyond fixed or static views of travel satisfaction and well-being, to consider it as a dynamic and evolving process. The study draws on video-recorded ride-along interviews conducted in Barcelona, Spain, and employs a dual qualitative approach combining (1) discourse analysis of participant narratives and (2) observational analysis of embodied practices captured on video.

### 5.2.2. Background

#### 5.2.2.1. E-scooter and travel satisfaction

In the last few years, researchers have started to examine the travel satisfaction associated with different micromobility modes (Mouratidis et al., 2023). So far, initial findings have generally revealed high levels of satisfaction associated with e-scooter usage, primarily linking this sense of fulfilment to cognitive and functional factors (Aman et al., 2021). Based on stated preference set-ups, the literature has presented e-scooters as a practical mode of transport for daily commuting, enhancing travel independence and predictability in scheduling (Eccarius & Lu, 2018; Kopplin et al., 2021), while requiring minimal physical effort. This is in contrast to the inconveniences, slow pace, or crowdedness associated with traditional modes of transport (Hyvönen et al., 2016; Mitra & Hess, 2021b). E-scooter ease of navigation and comfort while driving (Kopplin et al., 2021), along with shorter trip duration (Bielinski & Wazna, 2020; Glavic et al., 2021), and enhanced route selecting capabilities (Cubells et al., 2023), have also been cited as factors that potentially contribute to user satisfaction.

Beyond these functional factors, non-functional or sociopsychological aspects have also been found to play a significant role in users' engagement with these devices (Bretones & Marquet, 2022b). One of the most frequently cited non-functional factors linked to high levels of e-scooter satisfaction, is that of environmental awareness. According to Eccarius and Lu (2020) or Mitra and Hess (2021), for instance, being environmentally conscious, and hence using an environmentally friendly mode of transport is perceived as doing a "social good", which increases the gratification associated with the modal choice. Several studies have found individual perceptions of a positive and pleasant riding experience to also serve as motivation for adopting and using e-scooters for their daily commutes (Fitt & Curl, 2020; Hyvönen et al., 2016; Sanders et al., 2020; Sellaouti et al., 2019), highlighting how important it is to experience fun and freedom as part of the ride (Will et al., 2021). Similarly, the increased potential of exposure to the natural environment as well as the perception of physical activity have also been identified as addressing the connection between e-scooter use, well-being and mental health, especially for those users replacing sedentary modes of commuting, such as the car or bus. This analysis provides a valuable starting point from which to examine the potential benefits of e-scooter use for specific populations (Grant-Muller et al., 2023).

#### 5.2.2.2. The influence of the environment on e-scooter travel

Research has also taken steps in understanding e-scooter to the usage and network level. Primarily employing quantitative methods, such as analysing the open-source databases of e-scooter companies or through ad-hoc surveys, existing literature provides valuable insights into, for instance, the distribution of ridership (S. Bai & Jiao, 2020; Hosseinzadeh et al., 2021b), the most frequent paths (Haworth et al., 2021; Zakhem & Smith-Colin, 2021; W. Zhang et al., 2021), peak usage hours (Foissaud et al., 2022; Mathew et al., 2019), or the impact of external factors such as weather conditions (Kimpton et al., 2022). In general, what most of these studies have in common is the recognition of a certain typology of cycling infrastructure as a critical factor for reaching minimum user volumes (Caspi et al., 2020; W. Zhang et al., 2021). E-scooter users seem to consistently favor dedicated, one-way, and well-lit cycling infrastructure (Caspi et al., 2020; H. Yang et al., 2022; W. Zhang et al., 2021; Zuniga-Garcia et al., 2021), while showing aversion towards similar kinds of urban elements, such as sidewalks (Bai et al., 2017) or the presence of traffic lights (Cubells et al., 2023a; Prato et al., 2018). However, e-scooter ridership is more nuanced than these general preferences suggest, with results often being context-dependent and not conclusive. In Austin, for instance, e-scooter riders were found to take detours so as to integrate urban greenness into their rides (S. Bai & Jiao, 2020), a behaviour also observed in Calgary, Canada (H. Yang et al., 2022). In contrast, in Barcelona, where e-scooters are privately-owned, although riders also take longer detours than other micromobility users, they do not do so to in a quest for exposure to urban greenery (Cubells et al., 2023a). This variety in findings seems to suggest that e-scooter riding decisions are indeed influenced by factors such as urban context or city layout. At the same time, it also seems to suggest that differences in access (i.e., whether riders use sharing services or they own a personal device) should also be considered as a factor likely to influence their behaviour, which would be adding another layer of complexity in understanding e-scooter travel experiences (Roig-Costa et al., 2024b).

Some other studies have employed more experimental setups and observational techniques to delve deeper into the nuances of e-scooter use at a more micro level, examining specific aspects such as riding vibration (Cano-Moreno et al., 2021), parking habits (A. Brown et al., 2020; James et al., 2019), and interactions with other road users (Che et al., 2021). Tuncer et al. (2020), for example, applied an ethnomethodological lens, using video recordings to illustrate how e-scooter riders dismounted and manoeuvred to secure the right of way, while also examining the reactions of both pedestrians and riders when confronted with the sudden presence of e-scooters. Similarly, Gibson et al. (2022) conducted in-depth interviews with e-scooter riders and pedestrians. Their thematic analysis highlighted the uneven and unfamiliar socio-spatial encounters between these groups, indicating that the presence of different transport modes with various navigation characteristics functioned as a modulator of public space users' navigation experiences.

#### 5.2.2.3. Affects and emotions in e-scooter travel experiences

While the environment is often analysed in terms of network coverage or infrastructural quality, recent research in mobility studies and emotional geography suggests that it also functions as an affective field, generating sensory cues, symbolic meanings, and emotional affordances that shape how people move and feel in space (A. Jensen, 2011; Roy et al., 2024). Despite significant progress in identifying environmental determinants of e-scooter route choices (Cubells et al., 2023a; W. Zhang et al., 2021), much of the existing research lacks explanations of the rationale driving these decisions. While it is firmly established that travel behaviour is influenced by specific events experienced during travel (Ettema et al., 2011), most attempts to uncover the motivations and subjective aspects behind riders' route choices remain largely hypothetical. Surveys have occasionally complemented behavioural data with users' self-reported perceptions of comfort or experience, but affective responses are often missed, particularly when relying on quantitative approaches. Furthermore, ex-post self-reports are prone to memory biases and lack the depth required to capture the subtleties of how e-scooter riders emotionally engage with the urban environment and with other public space users.

In particular, existing methods struggle to grasp how riders navigate the city, react to interruptions or affordances and position themselves within specific socio-material contexts, all of which can significantly shape emotions experiences. In response to this gap, Zeile et al. (2016), for instance, integrated bio-physiological sensors to identify urban areas where cyclists experienced heightened stress or emotional activation. While their work focused on bicycles, it demonstrated the potential of tracking affective peaks, such as fear and anger, linked to specific spatial configurations. E-scooter riders, too, experience a range of sensory and emotional reactions, ranging from exhilaration and calm to frustration or vulnerability, which eventually shape their broader mobility decisions (Kazemzadeh & Sprei, 2022). These affective responses can also be conditioned by the social dynamics surrounding e-scooter use. For some, riding is accompanied by a "social pull", a sense of personal identification and feeling of belongingness with the micromobility community (Huang, 2021), while others report negative social feedback, such as harassment and derogatory comments, which contributes to a persistent stigma (Gibson et al., 2022; Mayer et al., 2020). These type of interactions, described by Friman (2004) as *critical incidents*, tend to evoke strong emotional reactions and can significantly shape overall satisfaction, perceived safety, and long-term behavioural patterns.

Beyond understanding how social context influences rider emotions, it is crucial to examine how users are affected by their physical surroundings and by the strategies they use to navigate them. Emotions, though internal, are shaped by external environments and emerge through spatial experience, embodied practice and interaction with the built and social world (Roy et al., 2024). This makes it essential to explore how riders feel in place and how their travel satisfaction is mediated by urban infrastructure, regulation, spatial legibility and other environmental conditions. Given the current limitations in capturing such embodied and sensory layers of experience, this study adopts a mobile qualitative perspective aimed at uncovering the emotional and affective dimensions of e-scooter travel. By observing actual behaviour in situ and analysing discourse and gesture through video-recorded mobile interviews, we offer a more textured understanding of how spatial configurations influence riders' emotional wellbeing. In doing so, we aim to move beyond a static view of satisfaction and contribute to a more nuanced perspective on micromobility's role in shaping everyday urban experience.

### 5.2.3. Methods

#### 5.2.3.1. E-scooters and Barcelona: the particularities of the study-setting

This study was conducted in Barcelona, Spain, on the northwest coast of the Mediterranean Sea. Despite recent years have seen expansions of Barcelona's cycling infrastructure (reaching 268 km in 2025), the city inherits decades of car-centric urban planning (Miralles-Guasch, 2009; Walker et al., 2023). This historical legacy continues to shape how public space is distributed and contested, often limiting the harmonious integration of emerging mobility modes such as e-scooters. In such a dense and compact city, where space is a particularly finite resource, precisely due to concerns over the occupation of public space and related dysfunctions, in 2017 the City Council of Barcelona enacted legislation prohibiting free-floating e-scooter companies (e.g., Lime or Bird) from operating within the city's administrative boundaries (Ajuntament de Barcelona, 2017). While the ban was originally framed as a pragmatic measure to protect shared urban space, it unintentionally triggered a rapid increase in the popularity of privately owned e-scooters, with trips rising by 179.6% between 2020 and 2021 (EMEF, 2022).

At the regulatory level, privately-owned e-scooters in Barcelona must comply with specific municipal rules regarding both equipment and circulation. Riders are required to wear a helmet, and the vehicle must be equipped with both front and rear lights. Circulation is strictly prohibited on sidewalks and other pedestrian-only areas under any circumstance. Instead, users are allowed to travel on designated on-road cycle lanes, where they may circulate at a maximum speed of 25 km/h, although they are required to reduce their speed when approaching pedestrian crossings. When riding on sidewalk-integrated cycle lanes, the maximum permitted speed drops to 10 km/h. E-scooters are also permitted on single-platform streets, where the speed limit is capped at 20 km/h, and on pedestrian zones, where they may circulate at up to 10 km/h, but only in cases where their passage is explicitly authorized. In addition, they may circulate on zone 30 streets at a maximum of 25 km/h, and within parks, where speeds must not exceed 10 km/h (Ajuntament de Barcelona, 2024). This regulatory framework reflects an effort to integrate e-scooters into Barcelona's complex mobility landscape while ensuring safety and coexistence with other users. However, it also imposes constraints that may require riders to adjust their speed frequently and remain alert to changes in the permissibility of different spaces, contributing to a discontinuous and highly contingent riding experience.

#### 5.2.3.2. Participants recruitment and protocol

During June and July of 2022, the first author conducted individual interviews with 12 e-scooter riders in Barcelona, all of whom had previously participated in earlier stages of the project (Roig-Costa et al., 2021) and had agreed to be contacted in future phases of the investigation. These participants were reengaged via WhatsApp and invited to take part in a follow-up interview, with no incentives provided. According to Hennink et al. (2017), code saturation (which represents the point which no additional codes emerge from the data) is generally reached after 9 participants. After performing a preliminary coding of the 12 interviews, the research team reached a consensus that no substantially new codes were emerging, and that code saturation had been achieved. Therefore, the number of participants was considered sufficient for the study exploratory goals.

Due to the specific legal framework in Barcelona, participants in our study were all users of privately-owned devices. This should be noted as we consider it to be by no means an insignificant detail in the study of behaviour and the relationship with the urban environment. The 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 received ethical approval from the Research Ethics Committee of the Universitat Autònoma de Barcelona (CERec, ref. 3656), ensuring that all procedures related to recruitment, informed consent, data collection, and data management complied with established ethical standards and respected participants' rights, privacy, and confidentiality.

#### 5.2.3.3. Interviews

The data collection involved a dual approach: a mobile interview conducted during e-scooter rides and a follow-up static interview. Prior to the ride, participants completed a short survey that collected basic personal and background information (age, gender, years of e-scooter use) alongside evaluative questions about the forthcoming trip, including the Satisfaction with Travel Scale (STS)[3] (Ettema et al., 2011). Administering the STS at this early stage allowed to capture participants' anticipatory evaluations of the trip, while also providing them with a more nuanced emotional vocabulary capable of

[3] Grounded in subjective well-being research, the STS captures both affective and cognitive dimensions of travel experience. The affective component refers to individuals' emotional state during travel and follows the affect circumplex model (Västfjäll & Gärling, 2007), which categorises emotions along two axes: valence (pleasant–unpleasant) and activation (high–low). Affective well-being is captured through contrasting items that range from positive deactivation (e.g., relaxed, scored as -4) to negative activation (e.g., time-pressed, scored as 4), and from positive activation (e.g., alert, scored as 4) to negative deactivation (e.g., tired, scored as -4). The cognitive dimension, in turn, assesses the overall appraisal of the trip.

triggering precise reflections during the ride-along itself (Bissell, 2010; Hein et al., 2008). Table 1 summarizes key characteristics of the participants and their trips, including gender, age and years of riding experience, information which provided important context. Information on trip characteristics and participant attitudes can also be found. During this phase of the study, the research team accumulated a total of four hours of video and almost nine hours of interviews.

Table 14. Participants and trips characteristics

| Participant Code | Gender | Age | Riding Exp. (years) | Trip reason | Trip distance (km) | Trip duration (min) | Riding time (min) | Walking time (min) | Av. speed (km/h) | Max. speed (km/h) | Helmet |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ESC01 | Woman | 37 | 4 | Work | 1,5 | 10 | 6 | 4 | 9,93 | 25,02 | Yes |
| ESC02 | Man | 38 | 3 | Leisure | 2,6 | 5 | 5 | 0 | 12,08 | 22,15 | No |
| ESC03 | Man | 36 | 3 | Work | 6,7 | 32 | 26 | 6 | 9,40 | 31,78 | Yes |
| ESC04 | Man | 40 | 1 | Work | 2,6 | 12 | 11 | 1 | 8,56 | 24,42 | No |
| ESC05 | Man | 25 | 3 | Work | 5,4 | 24 | 24 | 0 | 14,82 | 30,45 | Yes |
| ESC06 | Woman | 32 | 4 | Work | 3,8 | 20 | 19 | 1 | 8,51 | 26,48 | Yes |
| ESC07 | Woman | 57 | 6 | Work | 4,2 | 28 | 16 | 12 | 8,09 | 28,06 | Yes |
| ESC08 | Man | 51 | 4 | Work | 3,9 | 27 | 25 | 2 | 10,49 | 20,87 | Yes |
| ESC09 | Woman | 54 | 2 | Work | 4,5 | 19 | 19 | 0 | 11,16 | 27,40 | Yes |
| ESC10 | Man | 38 | 2 | Work | 3,6 | 20 | 19 | 1 | 9,25 | 25,08 | Yes |
| ESC11 | Woman | 48 | 3 | Work | 1,9 | 11 | 10 | 1 | 7,49 | 20,16 | Yes |
| ESC12 | Man | 19 | 2 | Leisure | 2,6 | 11 | 11 | 0 | 12,59 | 27,07 | No |

Source: own elaboration

Mobile interviews

Ride-alongs were chosen to capture the embodied experiences of e-scootering, allowing the researcher and the participants to move through space together. This method offered a unique opportunity to explore e-scooter routes, spatial interactions, and user experiences, enabling discussions that might not otherwise arise (Wegerif, 2019). Participants were instructed to select a routine trip that they perform on a regular basis, ensuring the contextual relevance of the gathered insights. Drawing from methodology outlined in earlier research (Roig-Costa et al., 2025; Van Cauwenberg et al., 2018), and recognizing the challenges of maintaining a coherent conversation while riding an e-scooter, participants were advised against trying to engage in dialogue with the researcher. Instead, they were installed a microphone on their lapel and encouraged to share their thoughts and emotions using a think aloud method (Eccles & Arsal, 2017), without expecting a response from the researcher. To enrich participants reflections, the narrative was boosted using targeted questions posed at natural pauses such as red traffic lights or intersections.

In practical terms, this translated into a layered recording setup, capturing participants' verbalised reflections alongside their embodied movements through space. Participants verbal statements and reflections were recorded using a digital voice recorder (Sony ICDPX240.CE7). Additionally, the whole trips were video-documented with a compact camera (GoPro Max) installed on the researcher's e-scooter handlebar and simultaneously tracked using a GPS datalogger receiver (Qstarz BT-Q1000X), which logged the exact location of participants every 5 seconds. This approach draws inspiration from shadowing methodologies (Jirón, 2011), which emphasize the value of accompanying participants in their daily trajectories to gain insights into their embodied mobility practices and the affective and spatial dynamics of movement. By using this approach, researchers were able not only to prioritize participant safety, but also to preserve the organic nature and characteristics of the trip. All participants, without exception, travelled via e-scooters as part of their daily routines, and had been doing so for at least one year. Map 5 displays participant ESC01 trip. Additional specific trips for all participants in our study can be found in the Supplementary Materials.

Map 5. Participant ESC01 trip


Source: own elaboration

<u>Static interviews</u>

At the end of the ride-along, the video camera was turned off, and a semi-structured interview based on the previous trip took place with each participant. This lasted approximately 25 minutes and involved a discussion of the attitudes, decisions and behaviours engaged by participants during the recorded trip. Together, these measures offer a nuanced understanding of participants' immediate experience of travel.

5.2.3.4. Data analyses

The analysis was structured in three distinct stages: an initial behavioural stage, a subsequent discursive stage, and an integrative phase anchoring discourse to space. All phases were conducted collaboratively by the three co-authors. To ensure analytical rigour and incorporate multiple perspectives, the initial counting and coding and classification were performed independently by two researchers, followed by consensus-building sessions. Triangulation was applied by cross-referencing video, audio, and field notes to identify recurring patterns. Additionally, peer review sessions with colleagues external to the core research team were conducted to critically discuss emerging themes and validate interpretations.

Behavioural and spatial interactions

The first stage of the analysis focused on observable travel behaviour and relied on two complementary sources: video footage and GPS tracking. Video recordings of the ride-along interview were downloaded to the researcher's laptop the same day the interview took place. These recordings were then reviewed to categorize user behaviour, with particular attention to how participants navigated the city, identifying patterns, deviations and responses to street infrastructure. In parallel, GPS spatial data was processed using the Human Activity Behavior Identification Tool and data Unification System (HABITUS) software, supporting a geolocated reconstruction of movement that enriched the behavioural assessment. Behavioural indicators, such as speed changes, manoeuvring tactics, and adaptation to environmental cues were audited to capture recurring actions or anomalies, as detailed in "Appendix A Supplementary Material". Participant photographs derived from the recorded videos are included to further illustrate the findings.

Discursive content

In the second stage, the thematic analysis of participants' discourses took place. The transcription process involved both the mobile (during the trip) and static interviews, and was initiated within hours of each interview and completed within a week to ensure the accuracy and retention of nuances. 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. Following the approach outlined by Sandelowski (2001) and Van Cauwenberg et al. (2018), qualitative data was then integrated with quantitative counts of participants who discussed specific infrastructural elements to support the description of our findings. Prevalence of these elements was represented as follows: "few" for elements mentioned by less than 25%, "some" for 25–50%, "a lot of" (sometimes "many" for readability purposes) for 50–75%, and "almost all" for over 75%. Participant quotes derived from the recorded interviews were included to further illustrate the findings.

Anchoring discourse within the spatial dimension

The final stage of analysis integrated the discursive and behavioural layers by synchronising participants' verbal expressions with specific spatial contexts observed during the ride-along. This temporal alignment allowed the researchers to interpret spoken reflections not as isolated narratives but as situated responses to real-time experiences of movement and urban form. By anchoring discourse in its spatial and embodied context, this approach deepened the interpretive richness of the thematic analysis and revealed affective patterns that might otherwise remain undetected.

### 5.2.4. Findings

This section presents the results of the inductive qualitative analysis combining direct observation, thematic coding, and the interpretive integration of both.

Among the patterns that emerged, *satisfaction* stood out as the most consistent and conceptually central theme across participants' accounts. *Cycling infrastructure* and *adaptive strategies* appeared as key elements shaping, reinforcing, or challenging this satisfaction in different urban settings. Drawing on the framework of the Satisfaction with Travel Scale (STS) (Ettema et al., 2011), satisfaction is here understood as a multidimensional construct that includes both cognitive and affective components. Cognitive evaluations refer to users' assessments of the general quality, convenience, and efficiency of the travel experience. In parallel, affective components are based on the two-dimensional model of emotional response proposed by Russell (1980, 2003), which distinguishes emotions according to their valence (pleasant–unpleasant) and level of activation (high–low).

#### 5.2.4.1. E-scooter ridership: when functionality fuels satisfaction

As already mentioned, a highly recurring theme during the interviews was the satisfaction associated with e-scooter use, observation that aligns with previous reports and research on privately-owned e-scooters (Boo et al., 2023; EMEF, 2022; Nikiforiadis et al., 2024; Roig-Costa et al., 2024b), In almost all cases, and especially during the static part of the interviews, these observations were justified with functional factors, such as *"the convenience of door-to-door travel"* (ESC09) (Mitra & Hess, 2021b), *"the minimal amount of physical exertion required during transportation"* (ESC10) (Eccarius & Lu, 2020b; Sanders et al., 2020), or *"the time savings compared to other modes of transportation"* (ESC01) (Carroll, 2022; Glavic et al., 2021). Each of these factors contributed to a perceived high standard of trip quality and a cognitive assessment that e-scooter travel *"worked well"* and was the *"best"* transport option they could think of. Expressions such as *"You see, it is fantastic"* (ESC01, ESC09) or *"It is the best decision that I have taken"* (ESC05) were recorded during the rides, revealing general feelings of gratification. This connection between travel satisfaction and practical benefits confirms the significance of the functional aspects in shaping the satisfaction associated with e-scooter travel (Aman et al., 2021).

#### 5.2.4.2. The affective dimension of e-scooter ridership: cycling infrastructure as a modulator

Rather than treating emotions as fixed responses or satisfaction as a final outcome, this section explores how the embodied act of riding an e-scooter gives rise to a dynamic range of affective states, states which are entangled with the material and spatial conditions encountered during the trip. These emotions do not emerge in a vacuum; instead, they unfold through the interaction between users' personal dispositions, infrastructural settings, and the contingencies of the ride. In this sense, affect is not simply felt, but produced, shaped by the rhythm of movement, the negotiation of speed, and the presence or absence of separation from other vehicles, for instance. In what follows, we draw from participants situated accounts to trace how emotions manifest through the ride. The analysis is structured around three types of infrastructural configurations and the affective atmospheres they tend to generate: those associated with positive engagement, those marked by ambivalence, and those that give rise to tension and alertness.

Infrastructural configurations supporting positive affective states

A key finding emerging from the ride-along interviews is that certain infrastructural configurations, particularly those involving spatial segregation, unidirectional flow, and sufficient width, were consistently associated with positive emotional states among e-scooter users. While these elements are often discussed separately in planning literature, our analysis suggests that it is their co-presence that enables a sense of ease, confidence, and fluency in micromobility travel.

*"I prefer the one that is purely segregated".* ESC07' clear words summarize the strong preference that almost all participants expressed for spatial segregation. In line with prior research (Cloud et al., 2022; Fonseca-Cabrera et al., 2021; Glavic et al., 2021), a lot of participants in our study described segregated bike lanes as safer spaces that reduced the constant sense of fear of collisions or close calls. Additionally, our observations suggest that navigating these environments tends to elicit positive deactivation emotions. In this sense, many participants associated segregation with feelings of "calmness" or "relaxedness", emotional states commonly used in standardised and multidimensional constructs to conceptualize satisfaction (Bergstad et al., 2011; Ettema et al., 2011; Olsson et al., 2012). As ESC02 noted, *"The type of bike lane that makes me feel more comfortable is the one that is segregated, clearly. Either unidirectional or bidirectional but segregated. […] I feel more calmed*". These responses point to the role of the cycling infrastructure not only in shaping perceived safety, but also in producing emotionally supportive travel environments that contribute to the overall satisfaction of e-scooter users.

Despite ESC02's ambivalence regarding directionality, almost all participants expressed a clear preference for unidirectional bike lanes, compared with two-way or mixed-traffic environments, aligning with prior studies highlighting their benefits in terms of clarity and reduced conflict (Caspi et al., 2020; W. Zhang et al., 2021; Zuniga-Garcia et al., 2021). ESC04 and ESC06, for instance, described one-way lanes as more "predictable", while ESC08 defined them as "ecosystems with potential to reduce conflict". Interestingly, these perceptions contrast with recent findings by Nello-Deakin (2025), who, using injury data from Barcelona, reported slightly higher injury rates on one-way bike lanes compared to two-way ones. In our study, however, unidirectional cycling infrastructure was frequently associated with positive affective responses, particularly among women, such as feelings of “confidence” and “calm”. These emotions were not only verbalized during the interviews but also observed through participants’ body positioning and riding behaviour, adopting more central lane use or displaying more relaxed postures (see Figure 23). Such embodied responses suggest that the perception of safety and emotional comfort does not necessarily align with objective measures of risk.

Bike lane width emerged as another factor shaping emotional responses during e-scooter travel. Almost all participants expressed a strong preference for wide cycle lanes, associating them with “comfort”, “freedom of movement”, and a general “sense of ease”. Wide lanes allowed riders to maintain a steady pace without feeling constrained, fostering a relaxed and fluid riding experience. This was especially evident during overtaking situations (moments that, in narrower lanes, were described by some participants as “tense” or “anxiety-inducing”). Within wider lanes, participants reported feeling “at ease” when overtaking slower users or being overtaken themselves, as the additional space reduced the likelihood of friction or abrupt manoeuvres. A few participants also mentioned that wide lanes promoted a sense of shared responsibility and mutual respect, as there was “space for everyone to move” (ESC06). In contrast, narrow sections were frequently associated with verbalised or visible signs of irritation, hesitation, or body tensing, as noted in ESC08’s words *“Here the lane narrows, usually there is few space for two to fit. I know that most people here don't overtake. You see, occasionally someone does, like now that one, but then frictions happen.”* The comparison between both settings revealed that width is not just a functional attribute but a modulator of emotional states, with wider paths often enabling calmer, more cooperative interactions among micromobility users. As ESC01 noted, summing up a widely shared view: *“Wide lanes are marvellous”*.

The combined presence of segregation, unidirectionality and lane width, as earlier mentioned in this section, was particularly appreciated by participants, especially in high-traffic areas, as it created a protective buffer from motor vehicles (see Figure 23). These features consistently fostered emotional states linked to positive deactivation, such as “calm” and “confidence”, evident not only in participants' verbal accounts and body language, but also in spontaneous behaviours like whistling or humming, actions often interpreted as markers of heightened emotional engagement or enthusiasm (Berger & Motl, 2000; Buhrmester, 2013). Some participants described these segments as moments of peace or minor daily pleasures, often mentioning sensations such as “the wind in my face” (ESC09) or expressing that these stretches were their “favourite part of the ride” (ESC11). Enjoyment here took on an almost meditative or restorative quality, what could be termed light or everyday fun, emerging not from thrill-seeking but from a sense of ease and fluidity in the urban environment.

Figure 23. Participant ESC01 riding through a dedicated, unidirectional, and wide bike lane.

Source: author’s own

Yet, enjoyment was not always passive or tranquil. In some cases, few participants associated fun with speed, agility, and playful negotiation of space. This more active and sometimes transgressive form of fun, closer to excitement or euphoria, was especially present among younger riders, for whom the e-scooter ride was sometimes described as an "escape" or "game." One participant reflected: *"I love riding an e-scooter. I mean, I really like the e-scooter. I really have a good time. [...] I really like going a little like that... if I see something, dodging it. Not playing, because deep down [the e-scooter] is a vehicle, but almost [playing]. I have a good time. Of the vehicles I've used, the e-scooter is the one that I've enjoyed the most".* This playful dimension, while emotionally positive, also hinted at behaviours that challenged formal or expected norms of circulation, particularly when cycling infrastructure permitted greater freedom of movement.

While these reactions suggest that infrastructural conditions can help generate emotionally supportive environments for e-scooter travel, they also reveal a potential paradox: in some cases, these same conditions appeared to foster overconfidence, particularly among specific user profiles. Increased speeds or riskier manoeuvres, for instance, were more frequently reported and observed across younger male participants, indicating that positive affective states, especially those involving excitement or euphoria, can lead to behavioural excesses. In this sense, cycling infrastructure not only shapes emotional geographies by reducing stress, but can also produce forms of positive activation that translate into unsafe riding practices (see also Cubells et al., 2023b; Gioldasis et al., 2021).

Infrastructures of ambivalence: when design elicits divergent emotional responses

Although segregated cycling infrastructure is often perceived as the most effective and widely requested design solution, its implementation becomes particularly challenging in compact cities like Barcelona, where planners navigate constraints related to limited public space (Nikitas et al., 2021; Tzamourani et al., 2022). In such spatially restricted environments, urban planners frequently turn to space-sharing strategies, which not only offer a pragmatic response to spatial limitations but also support the multifunctional role of streets as places of social interaction (Diemer et al., 2018; Tsigdinos & Vlastos, 2021). A representative example of this approach is the implementation of bicycle sharrows: maximum 30km/h one-way streets where bicycles and motor vehicles share the same lane. According to Tzouras et al. (2024), these designs function as compromise solutions aimed at balancing the needs of different users. By enabling their coexistence within the same space, such configurations are believed to promote more uniform travel speeds and smoother interactions among users (Kaparias & Wang, 2020; Karndacharuk et al., 2013).

However, the everyday experience of riding in a dense city suggests that the benefits highlighted by Tzouras et al. (2024) are not shared equally among all users and should therefore be interpreted with caution. Supporting this, research by Cubells et al. (2023b) observed that while men are more likely to use mixed or shared spaces, women riding e-scooters tend to favour routes with dedicated cycling infrastructure. While aligning with these findings, our ride-along interviews offered further insight into how shared infrastructures are differently inhabited across all e-scooter users. In particular, notable gendered differences emerged in how such environments are perceived and navigated. While almost all male participants displayed confidence and assertiveness in their use of shared lanes, often positioning themselves centrally as a way of maintaining control over interactions with motor vehicles (Figure 28), some female participants tended to adopt more cautious strategies. This bodily positioning was, most of the time, the result of a deliberate and conscious process, as illustrated in the following statement:

> *"Let him wait [in reference to a car approaching from behind]. I'm doing fine, I'm going at the right speed. I place myself in the center so that he doesn't overtake me, I'm riding at 25km/h in a street of 30, let him wait. This way I don't give him any option to overtake me."* (ESC03).

In contrast, as also observed in Figure 24, women were more likely to keep to the right edge of the lane, seemingly in search of a perceived buffer zone that might offer protection from passing motorized vehicles. Some of them accompanied this spatial behaviour with expressions of "discomfort", "fear", or "stress", emotional states consistent with what can be described as negative activation, the opposite of satisfaction. While these differences in travel behaviour have traditionally been attributed to women's greater risk aversion (Graystone et al., 2022; Prati et al., 2019), more recent studies argue that social constructs of gender and power dynamics at the bodily level provide a more nuanced explanation (Ravensbergen et al., 2019). From the perspective of performativity and embodiment theories, men draw on internalised norms of entitlement and confidence that legitimise their presence on the road, whereas women's more cautious positioning reflects a need to minimise exposure and maintain a sense of personal safety (Cubells et al., 2023b; Heim LaFrombois, 2019a). Echoing findings by Sersli et al., (2022) on cycling and women in Vancouver, Canada, several female participants in our study reported "feeling in the way", a sentiment that reflects how public spaces have long been constructed as masculine and purpose-driven domains, leading women, through socialisation processes, to internalise the idea that their presence in such spaces is illegitimate or should be discreet and unobtrusive (Heim LaFrombois, 2019a; Sayagh & Dusong, 2022). Our observations suggest that designs perceived as safe by male e-scooter riders might are not necessarily experienced as such by female riders, an asymmetry also noted by Xie & Spinney (2018) in the context of urban cycling. The perception of space-sharing strategies as neutral or inclusive must therefore be critically re-evaluated in light of these embodied and emotional differences in user experience.

Figure 24. Tendencies when riding in a 30km/h bike sharrow. Above, females. Below, males.


Source: author's own

Bidirectionality within bike lanes, which allows bicycles and e-scooters to flow in both directions on a single side of the road, emerged as another design feature where men and women shared different concerns. In scenarios such as those illustrated in Figure 25, where direct encounters with other actors were more likely to occur, it was observed that some women tended to slow their pace or to lean right more often. Indeed, a lot of female participants expressed a need to pay "increased attention" when using two-way lanes, concern only expressed by a few men. Emotional responses such as "alertness" and "stress" were more likely to co-occur in these settings, particularly among female participants, who often described two-way lanes as requiring "heightened attention" or "caution". As ESC09 summarised: *"I'm a little bit afraid that it's two-way, but it's practical"*.

This discomfort may be partly explained by the presence of fast-moving or risk-taking riders in these environments, behaviours that tend to disproportionately affect those travelling at moderate speeds, often women (Balkmar, 2018; Sersli et al., 2022). Observational data from the ride-alongs reinforce this interpretation: across the video material, overtaking manoeuvres were predominantly performed by male riders or directed at female riders, revealing contrasting dynamics in confidence, space negotiation, and pacing (see Supplementary Materials for more details). This pattern resonates with findings by Cubells et al. (2023b) and Arellano & Fang, (2019), who noted that male e-scooter riders not only travel at higher speeds than any other group using cycling infrastructure, but also tend to exhibit more careless attitudes. Once again, these gendered contrasts in behaviour and emotional response appear to be shaped by broader social norms, cultural expectations, and systemic privilege, which collectively grant men greater ease and entitlement in public space. Worrisomely, these forms of careless masculinity, embodied through speed and disregard for others, can actively dissuade potential users from sharing the space, thus undermining the inclusive potential of micromobility and its contribution to more sustainable urban mobility futures.

Figure 25. Female participants leaning to the right side of a bidirectional lane when crossing with another cycle lane user.

Source: author's own

Infrastructures disruptions and the production of negative affect

Finally, we observed that certain design elements consistently triggered negative emotional responses among participants. One of the most frequently mentioned (almost by all participants) was the placement of bike lanes on sidewalks. Participants such as ESC07 and ESC09 reported issues like "lower surface quality" and "increased frequency of vibrations", which undermined perceived comfort and safety. These discomforts were partly attributable to the smaller wheel diameter of e-scooter (Ma et al., 2021; Tzouras et al., 2023). However, most concerns stemmed from interactions with pedestrians, described by ESC03 as *"chaotic and confusing"*. In that sense, almost all participants verbalized difficulties in making their trajectories predictable, which hindered effective cooperation with pedestrians (Tuncer et al., 2020). The slower, stop-start riding pattern required in these settings disrupted the flow of movement (Figure 26), with few participants even describing these lanes as "suicidal" (ESC05), opting instead to share roads with cars despite the increased risk. These anxieties were most often tied to fears of harming pedestrians in narrow, contested spaces. Indeed, existing evidence shows that pedestrians involved in e-scooter collisions face disproportionately severe consequences, including higher rates of head, face, and neck injuries, traumatic brain injuries and prolonged hospitalisations than riders themselves (Siman-Tov et al., 2017).

Fig. 26. Participants foot positioning.

Source: author's own

Another significant design issue pointed by almost all participants was the lack of continuity within the cycling network. During our interviews, nearly all participants highlighted examples where dedicated cycling infrastructure was either absent or ended abruptly, resulting in fragmented and inconsistent riding experiences. Similar concerns have been raised in urban cycling research, which shows that discontinuous infrastructure not only disrupts physical flow but also produces stress and uncertainty among riders (Aldred & Jungnickel, 2014; Van Duppen & Spierings, 2013). These sudden interruptions and disconnections among cycle lanes sometimes forced participants to dismount and walk long distances alongside their e-scooters, triggering most of the time negative emotional states such as frustration or a sense of being fed up (Figure 27). This aligns with broader findings suggesting that network coherence is essential for creating a sense of safety, predictability, and trust in the system

(Forsyth & Krizek, 2011; Pucher & Buehler, 2012). This frustration was vividly illustrated by ESC07, who vehemently described an example where a cycle lane suddenly ended: *"You see, here? There is a piece of bike lane and suddenly it disappears. It is brutal. There is no continuity. No continuity! What am I supposed to do?"*.

Figure 27. Participants "walking the e-scooter" facing lane discontinuity.

Source: author's own

#### 5.2.4.3. Adaptive strategies and the pursuit of satisfaction beyond infrastructure

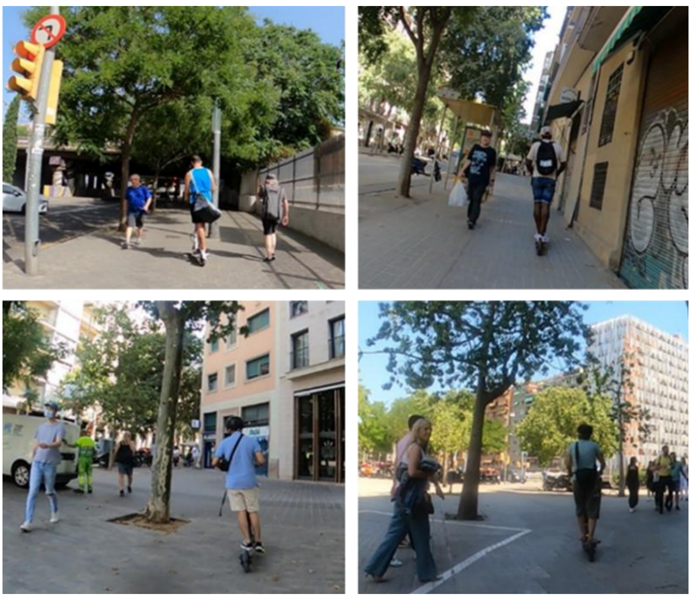
Despite frequent encounters with infrastructural shortcomings, most participants reported consistently high levels of satisfaction with their e-scooter use. This paradox can be understood through the lens of adaptation: rather than simply enduring deficiencies, many riders dynamically responded to spatial constraints using a repertoire of flexible and, at times, informal or illegal tactics. These strategies, ranging from minor rule-breaking to legal status-switching, often gave rise to affective states such as confidence, relief, or even playful satisfaction, suggesting that positive emotional experiences are not always infrastructure-enabled but sometimes tactically produced through situational responses to constraint.

Illegally engaging in minor infractions

Analysis of video footages revealed that actions such as sidewalk incursions, counterflow riding, or red-light skipping were recurrent informal strategies across most participants (see Figure 28 and Figure 29). These acts were not merely expressions of frustration with infrastructure (as in Buehler et al., 2021), but also moments of recalibration, instances where riders sought to restore flow and regain affective control over their trips. As ESC02 casually remarked while steering onto a sidewalk, *"And here we go again up on the sidewalk to avoid this bus lane. Whoops!"*, the act was both transgressive and routine, a spatial negotiation shaped by convenience and time pressure. Importantly, most riders demonstrated awareness of their positionality within contested spaces. Lower speeds on sidewalks and efforts to avoid pedestrian disruption were common, aligning with Mayer's et al. (2020) findings on risk mitigation. Yet this awareness did not always translate into guilt; rather, participants framed these infractions as necessary adaptations to an inflexible system. Echoing Prato et al. (2018), red-light running, for example, was described by few participants as a logic of efficiency rather than rebellion, *"I skip this one because there's no one here. I feel stupid stopping in the middle of nowhere"* (ESC04). Here, minor infractions emerge not simply as acts of individual risk-taking, but as embodied responses to infrastructural misalignment with user expectations and mobilities.

Rather than interpreting such actions solely through the lens of non-compliance or safety risk—as common in micromobility studies focused on deviant behaviour (Boua et al., 2022; Useche et al., 2022)—we approach them as tactical responses to constraint. Drawing from de Certeau's (1984) concept of "tactics", these behaviours can be seen as everyday acts of spatial improvisation, through which users temporarily subvert the logics the strategies in the city design and governance. While strategies, in de Certeau's terms, reflect the institutional production of space (through maps, plans, and regulatory frameworks), tactics represent how individuals rework these structures from within, carving out temporary routes of continuity, control, and affective coherence in a fragmented landscape. This tactical dimension is deeply entangled with emotion: satisfaction, relief, and playful pleasure arise not in spite of the infraction, but through it. Echoing Anderson (2014) and Matteis (2020) such affective geographies of movement are not confined to smooth infrastructure but emerge through contingent and situated encounters with the urban environment. While previous studies have documented similar behaviours (Lind et al., 2021; Ma et al., 2021; Tuncer et al., 2020), our findings offer a distinct contribution by situating these practices within the affective and experiential dimensions of travel. Drawing on video-recorded ride-alongs, we show how minor rule-breaking operates as a practical strategy to recalibrate disrupted journeys, revealing how adaptive behaviour becomes key source of user satisfaction under constrained conditions.

Figure 28. Participants illegally riding the sidewalk.



Source: author's own

Interestingly, this sense of control sometimes tipped into a perceived legitimacy to bypass norms, particularly among a few younger male riders. ESC05 exemplifies this when stating: *"Why have I bought an e-scooter for? I have deserved my right to commit certain irregularities. Also, I have the control."* This notion of entitled mobility resonates with findings from Boua et al. (2022) and Gioldasis et al. (2021), who associate overconfidence and a heightened sense of control with increased risk-taking. Yet what stands out here is not only the behaviour, but the emotional narrative attached to it: satisfaction, relief, even playful pleasure are triggered not despite the infraction, but through it. These affective geographies are therefore not confined to smooth or protected cycling infrastructures; rather, they emerge dynamically from users' capacity to adapt, bend rules, and navigate around constraints. Such tactical infractions can be read as acts of spatial reappropriation, momentary subversions of the logics inscribed into the city by institutional power through design, regulation, and control. In this light, the frictions of the city are not merely endured but reinterpreted as challenges to be overcome, with satisfaction arising precisely from the act of negotiating and momentarily reshaping these spatial prescriptions.

Figure 29. Up: participants riding counterflow; Down: participants running a red traffic light.

Source: author’s own

Legally changing status

In addition, some participants demonstrated e-scooter's ability to quickly switch between pedestrian and vehicle status, giving them the flexibility to adapt to changing conditions and optimise their travel experience. This chameleon-like nature enabled riders to select the most convenient infrastructure (whether pedestrian or bike-oriented) at any given moment, increasing their options and enhancing the likelihood of finding a route that suited their needs. Figure 30 illustrates a common practice: participants dismounting to cross a zebra crossing and walking on the pavement as a temporary pedestrian. In such cases, situations, participants would slow as they approached a red light, dismount at the front of the queue, and join the pedestrian flow at walking pace, avoiding disruption. Once on the pavement, they typically continued walking until they locate a bike lane, at which point they remounted and resumed riding. These small adjustments allowed riders to maintain momentum and avoid complete stops, as summarised by ESC07:

> "[...] *to win time. The e-scooter is practical, I don't need to...I can get off, keep on walking, get back on it"* (ESC07).

Figure 30. Participant dismounting to cross as a temporary pedestrian.


Source: author's own

Interestingly, and also observed by Tuncer et al. (2020), most riders employing these behaviours did not feel a need to justify their reasons for doing so, unlike in the case of skipping traffic lights. Nonetheless, many made conscious effort to minimise disruption to others. Most participants were generally keen to avoid being perceived as intrusive, dismissive of rules, or negligent, as demonstrated by their deliberate attempts not to cut across or disturb pedestrians while passing through pedestrian crossings. By transitioning between pedestrian and vehicle status, riders expressed a sense of agility and control that aligned with shifting urban conditions. This situational responsiveness appeared to reinforce their confidence in arriving on time, while also producing affective states such as enthusiasm and engagement. Enthusiasm often stemmed from the ability to bypass congestion or navigate crowded areas, while engagement was linked to the psychological aspect of maintaining a harmonious relationship with other road users and pedestrians. Riders who succeeded in managing their presence and movements (ensuring they did not disturb others or were perceived as rule-breaking) more often described a sense of satisfaction rooted in mutual respect and spatial awareness:

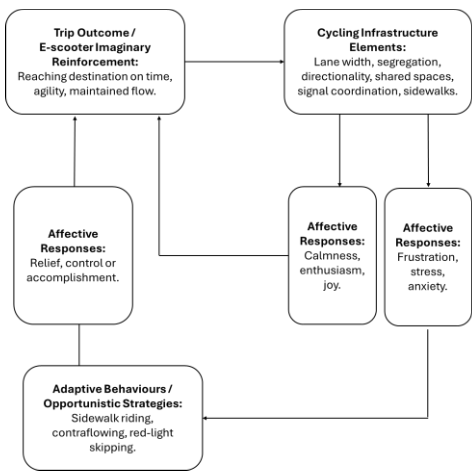
> *"The e-scooter is very versatile. It's much better, you've seen that I immediately get off and get on it... And I don't bother anyone, I have it very internalized. […] It is so easy […]"* (ESC01).

However, our findings also suggest that such adaptive behaviours, while often oriented to avoid trip inconsistencies and infrastructural shortcomings, inadvertently reinforce the broader 'monopolization of space' by cars (Horton et al., 2007). In Barcelona, where private motorised vehicles still dominate a disproportionate share of urban space, the growing popularity of e-scooters has not yet been met with proportional and targeted expansion of cycling infrastructure. As a result, congestion has increased in the already limited spaces allocate to active modes. Within this constrained landscape, the adaptations and coping strategies adopted by riders become particularly visible. Our video recordings reveal that when confronted with infrastructural gaps or obstructions, e-scooter users are often compelled to resort to pedestrian spaces, further intensifying the imbalances between active travel modes and motorized vehicles, and exacerbating tensions within active users, a pattern that ultimately reflects the persistence of automobility frames in urban infrastructure and planning (Glaser et al., 2020).

### 5.2.5. Concluding remarks

This paper contributes to the affective geographies of micromobility by examining the lived mobility experiences of 12 e-scooters riders navigating the dense and compact urban setting of Barcelona. Through in-depth (mobile) interviews and video analyses, we show how different elements of cycling infrastructure modulate emotional states and, in turn, influence the range and frequency of opportunistic strategies employed during travel. Our findings suggest the existence of a feedback loop, whereby the successful implementation of such strategies—particularly in response to infrastructural shortcomings—enables users to avoid disruptions, leading to a shift in affective atmosphere from frustration or anxiety to a sense of relief, control, or even accomplishment. We argue that these adaptive behaviours, by helping users reach their destinations efficiently, not only reinforce the perception of e-scooters as a convenient and agile travel option, but also contribute to the broader imaginary of the e-scooter as a mode of transport associated with autonomy, emotional reward, and everyday satisfaction (Figure 31).

Figure 31. Affective feedback loop of e-scooter travel experience in urban environments.




Source: own elaboration

Beyond efficiency, our results suggest that a trip is not merely a spatial transition, but also involves the construction and deconstruction of emotions shaped by the spaces traversed. The act of moving is inseparable from the experience of encountering and interacting with one's surroundings. Deficiencies in infrastructure not only shape behaviour, but also give rise to complex affective responses. These insights highlight the need for more nuanced transport policies that consider emotional dynamics as intrinsic to travel. However, policy alone is insufficient to drive meaningful change. Public awareness and culturally sensitive engagement, particularly around how individual agency and identity mediate mobility experiences, are equally essential. For instance, might the semi-illicit or transgressive status of e-scooters particularly enhance satisfaction for certain users, such as younger men? To what extent could rule-bending be an affectively charged practice that partly explains their appeal? These questions suggest the value of future research into the intersections of age, gender, and geography in shaping emotional landscapes of micromobility. These reflections also underscore the need for more tailored educational and infrastructural strategies aimed at addressing risks associated with youthful exuberance, overconfidence, and emotionally driven behaviours. Within this broader context, we argue that micromobility research must pay greater attention to the role of affect, not as a static or uniform, but as dynamic, fluctuating and influential for both short-term behaviours and shape long-term mobility patterns.

This research is not without limitations. One important consideration is the potential influence of the Hawthorne effect (i.e., where individuals modify an aspect of their behaviour in response to their awareness of being observed). Since the analysis draws on situated behaviours, the researcher’s presence may have affected riders’ decisions or emotional expressions. As one participant noted during a ride, "*Normally I would have skipped this one*," referring to a red traffic light, some degree of self-censorship may have occurred. Participants might have been more inclined to demonstrate law-abiding behaviour, potentially influencing their overall experience and self-evaluations. While efforts were made to minimise reactivity, such as maintaining a non-intrusive presence and only intervening at rest points, this limitation remains inherent to observational and mobile methodologies. Future studies may consider additional strategies to further mitigate observer effects when exploring affective and embodied aspects of travel in real time. Additionally, the modest sample size of the study limits the generalisability of our findings. Although the study provides rich, in-depth insights into the affective dimensions of micromobility, further research is needed to better capture the nuanced and intersectional dynamics of infrastructure use across different social groups and urban contexts. Future studies should consider diverse sampling strategies to explore how factors such as gender, age, class, or racialisation intersect with infrastructure availability, emotional experience, and behavioural adaptation.

Finally, these findings also point to a broader imperative for policy makers and urban planners: to read these seemingly minor or tactical behaviours not simply as deviations from the norm, but as affectively charged responses to infrastructural shortcomings and spatial inequality. Rather than treating them solely as issues of enforcement or regulation, they could be interpreted as everyday performances that expose the inadequate and uneven distribution of public space. From this perspective, e-scooter users' adaptive practices become an opportunity to critically reassess how urban environments are structured, and to design mobility policies that respond more equitably to the needs, rhythms, and emotions of all users.

# PART III – DISCUSSION AND CONCLUSIONS

# 6. Discussion

## 6.1. Discussion of the main findings

The aim of this section is to answer the research questions presented at the beginning of the thesis (Chapter 1) and to discuss together the main themes of the four case studies (Chapters 4 and 5). In order to facilitate interpretation, the discussion is structured according to the research questions and hypotheses.

**RQ1:** How does the emergence of micromobility modes influence the use of traditional transport modes, and what are the behavioural and environmental implications?

> *H1: Users of shared micromobility services are expected to have more multimodal travel behaviours than users owning private devices. However, differences in modal replacement patterns may not align as clearly with ownership status.*

This hypothesis is grounded in the understanding that the behavioural and ecological contribution of micromobility is deeply shaped by the broader mobility ecosystem in which it operates (Abduljabbar et al., 2021; Hollingsworth et al., 2019; Wang et al., 2022). Findings from the first two case studies confirm the first hypothesis (H1) by demonstrating that the relationship between micromobility and traditional transport modes is strongly mediated by the type of micromobility vehicle in question, particularly the distinction between privately owned devices and shared systems, which shape not only users' modal choices and patterns of integration in distinct ways, but also the distribution of the replacement schemes.

Until now, most research has addressed the interaction between micromobility and traditional transport within the scope of individual trips, either in terms of integration, as first/last mile connections to public transport (Bordagaray et al., 2016; Reck et al., 2022; Wong et al., 2020), or substitution, through counterfactual analyses of what mode would have been used if micromobility were unavailable (Reck et al., 2022; Ricci, 2015; Wang et al., 2022). By expanding the unit of analysis to the weekly level, the first case study of the thesis shows that ownership status significantly shapes how micromobility is integrated into users' broader mobility strategies. Specifically, this thesis reveals that while shared micromobility services tend to promote more flexible and multimodal travel behaviours, owning a micromobility device reduces the incentive to incorporate other modes to weekly modal mixes, promoting less rational and more habit-dependent mobility strategies. These findings resonate with results in earlier studies regarding private moped owners monomodal tendencies (Marquet & Miralles-Guasch, 2016). Surprisingly, however, our findings contradict the often-cited hypothesis that engagement with one shared micromobility service may act as a gateway to other shared services (Aguilera-García et al., 2020).

Previous studies in literature found that multimodal travellers are more likely to travel by public and non-motorised transport modes and less likely to travel by car (Buehler & Hamre, 2016; Diana & Mokhtarian, 2009). Although, as mentioned above, shared micromobility options in Barcelona foster greater multimodal behaviours than personal devices, the association between multimodality and sustainable modes does not hold exactly true for all sharing services. Instead, the type of titularity (being publicly participated or driven by venture capital investment) remains key in determining the whole configuration of weekly mobility strategies. In this sense, the first case study shows that subscriptions to publicly managed shared systems, such as docked bike-sharing systems, tend to encourage multimodal strategies involving, to a lesser from a greater extent, the use of public transport modes. In contrast, venture capital driven initiatives, like shared e-mopeds fleets, tend to play a more complementary role particularly among users who display frequent usages of private motorised transport. Aligning with Fu et al. (2025), our results therefore indicate that active micromobility services, such as bike-sharing systems, have the potential to promote more sustainable forms of multimodality.

The relationship between micromobility and traditional transport is further explored in the second article. Like most prior studies, this second publication retrieves the trip as the main unit of analysis. Emphasizing the context of regulatory fragmentation, a scenario that has received limited attention in the existing literature (which has generally assumed uniformity within policy frameworks), the study investigates the modal origins of micromobility demand. Using counterfactual approaches, the results align with previous research (Bieliński et al., 2021; Murphy & Usher, 2015; Teixeira et al., 2020), showing that most new micromobility users, regardless of vehicle ownership status, tend to shift from already sustainable modes, particularly public transport and active travel, and few of them from more polluting modes (McQueen et al., 2021). This is especially true in European cities, where car use is less dominant due to long-standing urban density and planning traditions (Wang et al., 2022). This phenomenon calls into question the potential of micromobility as a tool to fight climate emergency, at least in dense and compact urban environments, contrasting with the extended and popular belief that its emergence can help us decarbonize mobility and lower car-dependency in urban areas (D. Feng et al., 2020; Hardt & Bogenberger, 2019; The Nunatak Group, 2019).

The second article, additionally, highlights some mode-specific nuances in replacement patterns, suggesting at first glance that privately owned e-scooters are more likely than shared bicycles to attract users from private motorised modes. However, the incorporation of the subjective evaluation provides a more nuanced and plausible interpretation of the results. Our findings indicate that a considerable proportion of the already low number of former private mode users report lower satisfaction after switching to micromobility, with this being most noticeable for e-scooter users. In line with literature on travel satisfaction and long-term behavioural consolidation (De Vos & Witlox, 2017; Olsson et al., 2013), this casts further doubt on the extent to which these modal shifts are likely to consolidate over time, and consequently on micromobility's potential to challenge the dominance of private modes. These insights reinforce the importance of incorporating subjective assessments when evaluating micromobility travel dynamics and their implications for behavioural change, dimension that will be further explored in the discussion of research questions 3 and 4, where users' travel experiences and affective geographies are analysed in greater depth. In that research context, the implications of these replacement schemes extend beyond environmental considerations, as more micromobility users entering the urban space by shifting from public modes means adding more pressure on an already limited public and saturated public space. This spatial saturation, particularly in compact cities like Barcelona, influences not only how mobility is organized, but also how it is felt and experienced, reinforcing the link between infrastructural constraints, subjective perceptions, and the affective dimension of micromobility use.

**In conclusion, despite the theoretical promise of micromobility to contribute to more sustainable urban travel dynamics, current user strategies reveal that its actual positive impact remains limited.** Nevertheless, the evidence presented supports H1 by demonstrating that access to a shared service, particularly publicly managed systems such as docked bike-sharing, can encourage more rational, flexible and less habit-driven multimodal travel behaviours, practices that have been widely demonstrated to translate into environmentally desirable outcomes (Deschaintres et al., 2021; Wong et al., 2020). However, since most users currently shift from other sustainable modes such as public transport, the contribution of micromobility remains modest. The sustainability potential of bike-sharing systems will therefore depend on their future capacity to attract users away from private motorised transport, rather than merely redistributing demand across existing low-emission modes.

**RQ2:** To what extent does the emergence of micromobility reproduce or challenge sociodemographic inequalities in urban mobility access?

> *H2. The emergence of micromobility is expected to benefit a broad range of users. However, the distribution of these benefits is likely to vary significantly across micromobility modes, with shared systems often offering lower potential to reduce access barriers than privately owned alternatives.*

This hypothesis is grounded in the understanding that the social contribution of micromobility is closely tied to the wider institutional, spatial, and technological context in which it is deployed (Bach et al., 2023a; Spinney, 2020a). Findings from the first two case studies offer partial support for hypothesis 2 (H2) by showing that demographic uptake of micromobility is not evenly distributed, and that different modes tend to reproduce distinct patterns of inclusion and exclusion. While privately owned e-scooters appear to attract a more socioeconomically diverse user base, public shared systems, particularly bike-sharing schemes, demonstrate greater potential for gender and, to a lesser extent, age inclusivity. These variations suggest that the social sustainability of micromobility depends not only on user characteristics but also on the structural and regulatory conditions that shape access to each mode.

In Barcelona, micromobility vehicles are predominantly used by young, urban, and employed men (Bielinski & Wazna, 2020; Reilly et al., 2020b; Sardi et al., 2019). However, results in case studies 1 and 2 also indicate that these patterns vary considerably depending on the specific micromobility mode. Gender disparities are particularly marked for electrified vehicles, most notably shared e-mopeds and e-scooters, where women represent less than one third of users, challenging the assumption that electrified micromobility modes inherently reduce gender barriers (Bielinski & Wazna, 2020). In contrast, conventional bike-sharing systems present a less pronounced gender gap, echoing findings from previous studies (Fortes et al., 2024; Molinillo et al., 2019; Raux et al., 2017). Gender differences, however, extend beyond the decision to choose or adopt micromobility modes to the riding behaviour during the trips. Through embodied experiences of mobility, case study 4 expands existing research concerning spatial navigation decisions during micromobility trips (Arellano & Fang, 2019a; Cubells et al., 2023b). Findings uncover that most men e-scooter users navigate the city with relative ease and confidence, largely unhindered by concerns of space or conflict (Munt, 1995), contrasting with the experience of many women-identifying participants, who engage in more cautious riding behaviour as a strategy to minimise conflict and risk. Especially in shared spaces, such as bike-sharrows, or confined spaces, such as narrow two-way lanes, women are observed desisting more often to compete for their right to occupy that space than men. Similar practices have previously been observed among women cyclists when encountering aggressive male riding behaviours, which associate with the "feeling in the way" perception (Heim LaFrombois, 2019b; Sayagh & Dusong, 2022). This feeling stems from the cultural perception that public space has historically been framed as a masculine and productive domain. Women are often socialised to believe that their presence in such spaces is unwelcome or must be discreet and limited. According to our findings, the introduction of the e-scooter does not seem to cancel these gendered behaviours and internalized rationales. On the contrary, and especially within those potentially conflictive spaces where distinct speeds coexist, women tend to position themselves as inconspicuously as possible.

Age, an established predictor of both innovation uptake and sustainable practices (Bartels & Reinders, 2011; Novoradovskaya et al., 2020), also emerges as a key variable in micromobility adoption in Barcelona. Consistent with previous research (Soltani et al., 2019; Xin et al., 2018), micromobility users are significantly younger than the general population. In addition to the physical challenges related to balance, posture, or navigating traffic that already deter many older adults from engaging with micromobility, access to shared services often require digital literacy, smartphone ownership, and familiarity with app-based systems. These prerequisites disproportionately disadvantage older adults, calling into question the extent to which micromobility contribute to transportation justice, particularly in the case of e-scooters and e-mopeds (Campisi et al., 2020). However, under certain conditions, the promotion of specific types of micromobility can be related to slight improvements in inclusivity. In services that are more established or embedded within a certain urban mobility landscape, such as public bike-sharing scheme in Barcelona, the electrification of the fleet appears to be a viable strategy for retaining older adults within cycling dynamics. Interviews conducted in case study 3 support this interpretation, as one of the most frequently cited reasons for abandoning a bike-share trip was the unavailability of electric bicycles. While it is true that older adults do not yet feel adequately addressed by current micromobility offerings, and that shared electric bikes fall short in expanding access to new users in this demographic, their role in retaining ageing adults appears crucial. This finding aligns with previous research on private e-bikes in Australia (M. Johnson & Rose, 2015), which also identified electric assistance as a key factor in maintaining cycling habits among older individuals, either due to chronic knee pain, the physical exertion required to cycle uphill, or the additional time and effort associated with non-assisted cycling. Pedal-assist features therefore contribute to making bike-sharing a more viable and inclusive mode of transport.

However, despite this minor potential some specific shared systems have in mitigating age-based exclusion, sharing systems appear less effective in addressing class-based inequalities. As previously uncovered in many other cities, findings in the two first case studies show how shared micromobility remains predominantly accessible to middle- and upper-income groups (Eren & Uz, 2020; Reck & Axhausen, 2021; Shaheen & Cohen, 2019a). In Barcelona, public bike-sharing systems and shared e-mopeds tend to be concentrated within municipal boundaries and central urban areas, which are typically home to higher-income residents (Bach et al., 2023a), resulting in lower or null service availability for residents of peripheral and lower-income neighbourhoods. As shown in case study 2, this infrastructural divergence is additionally shaped by the specific regulatory landscape of the city. Unlike many Western cities, Barcelona excluded shared e-scooter services from its licensing process regularization, enforcing their removal from the public space. Consequently, e-scooter use in the city is not linked to app-based, pay-per-use models, which are often a barrier to low-income users, but to cheap low-quality devices purchased individually. This spatial and regulatory configuration, adding to the ability of private e-scooters to cross municipal boundaries (Dill et al., 2019b), position private e-scooters as an affordable and attractive option for many low-income residents to navigate fragmented metropolitan transport networks.

**In conclusion, findings from Barcelona suggest that micromobility is being adopted by a more socially diverse user base than in other cities, providing partial support for H2. However, this does not imply that access barriers**

**are being reduced across the board. On the contrary, these findings point to persistent and evolving patterns of socio-spatial segregation in micromobility use, driven largely by the interaction between regulatory frameworks, service coverage, and mode type.** In this context, shared micromobility services may inadvertently reinforce existing transport inequalities, with higher-income individuals benefitting from increased travel choices, while lower-income users face limited access and are more reliant on privately owned alternatives. As discussed in RQ1 and supported by Aguilera-García et al. (2024), the limited presence of shared options in the urban periphery may be contributing to the increased uptake of private micromobility in these areas. Unless addressed through future targeted policy interventions, this uneven expansion may deepen existing disparities rather than close them (Spinney, 2020).

**RQ3:** How do infrastructural conditions influence travel experiences across different vehicle types, and what are the implications for travel behaviour?

> *H3: Infrastructural conditions are expected to shape micromobility travel behaviour in distinct ways across vehicle types, with variations in how constraints are perceived and negotiated also depending on the characteristics of the mode.*

This hypothesis is based on perspectives that consider transport behaviour as materially situated and shaped by the affordances and constraints of the urban environment (Sheller, 2012; Urry, 2007). Extending on the findings of case study 2, which uncovered how limited provision (or, in some cases, the complete absence) of infrastructure filters or impedes access to micromobility for certain sociodemographic groups, findings from the third and fourth case studies support hypothesis 3 (H3) by showing that infrastructure not only determines access to different micromobility options but also modulates the quality of the travel experience itself, identifying common and discordant patterns across types of infrastructures and modes.

A core element shaping decisions for both docked bike-sharing and private e-scooter users is the desire to engage in safer trips in relation to traffic. This finding is not new and echoes existing evidence from other lightweight transport modes, particularly bicycles, across diverse geographies, from Northern Europe (Chataway et al., 2014; Van Cauwenberg et al., 2018), to Latin American contexts (Carvajal et al., 2020; Useche et al., 2023). In the present case, findings from both case study 3 and 4 show how users' sense of moving through a "safe space" is strongly shaped by the quality, rather than merely the quantity, of the cycling infrastructure. Mobile interviews confirm that features such as physical segregation, adequate separation from distinct speeds and sufficient lane width are consistently valued across both types of micromobility users. Despite not always corresponding to the spaces where the highest volumes of micromobility traffic are recorded (Arellano & Fang, 2019a; Cubells et al., 2023a), these elements are revealed as desirable environments that users actively prefer due to the protection they afford. Their effectiveness is significantly diminished, however, in the absence of proper network connectivity, which is essential not only to ensure that the travel experience remains as continuous and unfragmented as possible, but also to mitigate users' feelings of exposure and vulnerability, both in terms of personal risk, but also in terms of the unintended risks they may pose to others.

Additionally, both case studies reveal that when it comes to emerging transport modes, discussing infrastructure goes beyond material attributes such as lane width, directionality, or physical segregation. Rather, it encompasses a broader set of design and regulatory elements that structure mobility practices in culturally and politically significant ways. These include signage systems often oriented around the logic of automobility, traffic light timings calibrated for conventional vehicular speeds, or temporary shortages in infrastructure availability caused by construction works or maintenance interventions. Drawing on the work of Sheller (2015) and Cresswell (2010), such conditions can be interpreted as material expressions of a deeper cultural logic that continues to centre the car as the default mode of urban movement. For micromobility users, navigating the city is thus often marked by a series of subtle yet persistent reminders that they remain peripheral actors, "invited guests", rather than legitimate participants in the mobility system. These infrastructural absences or misalignments are not neutral: they shape how users move, how they feel, and how they evaluate the reliability and consistency of their trips. As Graham and Thrift (2007) suggest, it is precisely through such breakdowns or exclusions that the politics of infrastructure become visible. Findings in this case studies resonate with this view, showing how the micromobility experience is modulated not only by what infrastructure is present, but also by what is missing, and for whom.

A particularly illustrative example of how infrastructure becomes most visible through its absence or malfunction, and how such malfunctions unevenly affect shared bikes and e-scooters, are the docked stations. While literature had already examined the role of docking stations, research had primarily focused on distributional efficiency (J.-R. Lin & Yang, 2011), network optimization (García-Palomares et al., 2012b), or system capacity (Y. Ji et al., 2020; Wang & Akar, 2019) and its influence on trip generation. However, beyond the act of riding itself, findings from case study 3 highlight the contribution of bicycle pick-up and return processes, often considered peripheral stages and excluded from what constitutes the trip itself, in reinforcing the imaginary of the cyclist as a guest in a mobility system where the car remains the normative subject of design and regulation. Stations that are poorly integrated into the cycling network (situated adjacent to heavy traffic, lacking physical protection, or offering limited visibility) are not only seen as merely functional shortcomings that contribute to a sense of insecurity and disorientation, but also feed into a broader perception of the bicycle as an out-of-place mode, navigating an urban landscape primarily designed for cars. This effect is compounded in peripheral neighbourhoods, where the absence of service entirely configures a form of exclusion: not only are users unable to complete trips, but they are also denied the very possibility of developing everyday cycling practices, highlighting how absence itself produces "non-experiences" that shape mobility imaginaries.

In addition to infrastructural conditions, the design and material characteristics of the vehicles themselves also play a role in the construction of a more or less fragmented travel experience. For bike-sharing users, the physical heaviness of bicycles is frequently mentioned as a limiting factor, compromising manoeuvrability and increasing the physical effort required to complete trips. Functional aspects such as unresponsive brakes or misadjusted seats further exacerbated this sense of discomfort and unpredictability, reinforcing the perception of shared bicycles as not truly trustable systems, compromising not only users' sense of safety, but also their sustained use in the long term. By contrast, e-scooters riders improvise rhythms in order to avoid interruptions and continue moving, but also to protect themselves from the potential harms of sharing space with others (Gibson et al., 2022). As they cross the boundaries of transport spaces and adjust their motion accordingly, their modal status and sensory experiences become blurred, as they 'turn into a pedestrian and then turn into a vehicle.' This fluid modal identity emerges as a resource that help e-scooter users maintain flow and avoid exposure, and as hypothesised later in these discussions, contributes to the construct of the e-scooter as a more pleasurable travel experience.

**In conclusion, findings from case studies 3 and 4 provide evidence in support H3, demonstrating that, although perceived safety from traffic**

**remains the central element around which users articulate their mobility experiences, specific infrastructural features, as well as distinct adaptive strategies, contribute to shaping the travel experience in different ways.** While bike-sharing users are often resigned to accepting a fragmented travel experience, constrained by docking infrastructure and network limitations, and frequently required to adjust their pace, timing, and spatial practices to a system that does not accommodate them but merely tolerates them (Popan, 2020), e-scooter users tend to develop flexible adaptive strategies that allow them to overcome infrastructural shortcomings. These strategies may help explain why e-scooter trips are often perceived as more pleasurable compared to bike-sharing trips. This experiential divergence is further explored in the final research question (RQ4), which addresses how these different relationships with infrastructure shape the affective geographies of micromobility and influence users' overall satisfaction and wellbeing.

**RQ4:** How does infrastructure shape the affective geographies of micromobility travel, and what are the implications for users' overall satisfaction and wellbeing?

> *H4: The affective experiences and perceived wellbeing associated with micromobility use are shaped by both infrastructural conditions and vehicle-specific characteristics, with distinct emotional geographies emerging across different modes and sociodemographic profiles.*

The final research question (RQ4) marks a conceptual shift from infrastructural constraints and observable behaviours explored in RQ3 to the emotional dimension of travel. It foregrounds how users feel during their trips, how they interpret and respond to infrastructure-related challenges, and how these experiences inform broader perceptions of satisfaction and wellbeing. Drawing from non-representational theory (Anderson, 2009), infrastructure is here conceptualized not only as a physical setting, but as an affectively charged environment that mediates users' capacities to affect and be affected. The hypothesis H4 thus posits that affective responses are not homogeneous across modes. Rather, they are modulated by the physical and operational characteristics of each mode, giving rise to distinct affective geographies and ultimately influencing how satisfaction with the travel experience is constructed across modes.

Evidence from case studies 3 and 4 reveals that material and design differences between shared bicycles and e-scooters significantly condition how users relate emotionally to the same urban space. The fluid modal identity showcased by e-scooters serves not only as a tactical response to infrastructural shortcomings, but also as an affective element that may contribute to the e-scooter association with personal enjoyment (case study 2). These findings can be framed through Quéré's (2012) interpretation of the notion of "the work of emotions". According to this perspective, emotions are not internal states but embodied responses to problematic or intermediate situations, those moments when the environment interrupts the expected course of action and demands an inquiry (Tironi & Palacios, 2016). In micromobility trips, such moments occur frequently: a broken docking station, a bike lane suddenly disappearing, or ambiguous signage. While for bike-sharing users these interruptions are most of the time associated with uncertainty and frustration, for e-scooter users those often catalyse adaptive action that not only mitigate negative emotions but also contribute to a sense of agency and to an enhanced evaluation of the e-scooter use as pleasurable or viable alternative. In this way, as Bissell (2014) suggests, moments of disruption do not simply challenge rational decision-making but trigger emotional work that guides adaptation and evaluation. Users' capacity to affect and be affected is thus contingent upon their physical disposition, previous experiences, and expectations, but also upon the infrastructural and social configurations through which they navigate.

The emotional implications of micromobility are, at the same time, modulated by social positionality and intermodal relational dynamics. As mentioned above in RQ2, affective geographies are not distributed evenly. For instance, case study 3 uncovers how older participants feel excluded from the spatial micromobility dynamics if electric bicycles are not available, while case study 4 documents how certain women participants described heightened discomfort when riding through shared spaced or narrow lanes, experiences that resonate with longstanding critiques about the production of mobility space (Koskela, 2005). These affective atmospheres, emotional climates that operate beyond individual intention (Anderson, 2009; Bissell, 2010), mediate users' capacity to affect and be affected by the urban environment, contributing to divergent emotional alignments with infrastructure. Similarly, the affective experience of micromobility is relationally produced through interactions between users of different micromobility modes. For instance, several bike-sharing users reported instances of stress when forced to share narrow lanes with e-scooter riders, whom they described as unpredictable or disruptive. Interestingly, this affective tension was not reciprocated: e-scooter users rarely cited shared bikes as problematic. This asymmetry suggests that emotional geographies are not only vehicle-specific but also shaped by perceived modal hierarchies and social expectations within shared infrastructure.

**In conclusion, the interplay between infrastructural fragmentation, vehicle design, and emotional response offers insight into users' broader satisfaction and wellbeing.** While e-scooter riders often engage in adaptive strategies that maintain flow and mitigate exposure, thereby producing experiences often perceived as satisfying, bike-sharing users describe more fragmented, effortful, and disjointed trips. Factors such as station placement, bicycle weight, or misaligned brakes exacerbate this affective strain. These insights reinforce the central hypothesis (H4), showing that emotional geographies of micromobility are not only vehicle-specific but are relationally and infrastructurally situated. In this light, the affective domain is not a marginal consequence of micromobility, but a central mechanism through which satisfaction, behavioural decisions and wellbeing are produced.

## 6.2. General conclusions

A central conclusion of this thesis is that the use of micromobility cannot be understood in isolation from the types of vehicles offered, the profiles of the users who adopt them, and the structural conditions that mediate their use. The evidence presented in the four case studies reveals that ownership and system design significantly influence both behavioural integration and access. Notably, shared systems (especially those publicly managed) appear capable of disrupting well-established behavioural patterns by fostering rational, context-dependent decisions rather than merely reinforcing habitual routines, thus challenging dominant theories that depict travel behaviour as largely automatic or routine-based. However, while shared systems encourage more multimodal behaviours, they remain spatially and socially constrained, often reinforcing pre-existing inequalities. Privately owned vehicles, especially e-scooters, offer greater flexibility and territorial reach, but this same flexibility tends to favour individualised and sometimes exclusive mobility patterns.

From a social perspective, adoption patterns are uneven across gender, age, and class lines. Shared systems tend to reproduce barriers to access, while private e-scooters, due to their adaptability and absence of platform-based constraints, occasionally serve as functional workarounds in underserved areas. In environmental terms, the modal shift effect remains limited: many users adopt micromobility by substituting already sustainable modes such as walking or public transport, rather than displacing private motorized vehicles. Instead of supporting claims about the inherent sustainability of micromobility, this dissertation highlights how environmental and social impacts are conditioned by ownership models, regulatory environments and infrastructure design.

Another key contribution of the thesis lies in its nuanced treatment of infrastructure, not as a static background condition, but as an active terrain through which mobility is shaped, contested, and felt. Case studies 3 and 4 demonstrate that infrastructural conditions influence not only the feasibility of micromobility use, but also its emotional tenor and perceived legitimacy. While bike-sharing users more often encounter fragmented or frictional infrastructures that constrain their movements and generate frustration, e-scooter users display greater adaptability, mitigating these shortcomings through improvisational tactics. However, these different responses are not only shaped by vehicle characteristics but also by broader socio-material environments, including signage, visibility, and spatial configurations. The thesis therefore reveals infrastructure as a mediator of both mobility behaviour and affective alignment, reinforcing the need for transport research to engage more explicitly with the experiential and emotional dimensions of travel.

Additionally, this thesis highlights the importance of affect in shaping travel satisfaction and long-term behavioural dispositions. Drawing from non-representational theory, it argues that micromobility experiences are co-produced through an interplay of physical infrastructures, vehicle affordances, and social positionalities. Users' emotional responses, ranging from pleasure and agency to discomfort and exposure, are not peripheral to mobility, but integral to how it is lived and evaluated. These affective geographies are shown to be unevenly distributed: shaped by gender, age, and intermodal interactions, as well as by the affordances of specific vehicles. Notably, e-scooter users often articulate more pleasurable experiences, while bike-sharing users report greater friction and fragmentation. These findings suggest that emotional alignment with infrastructure plays a central role in how new mobility practices are consolidated. In doing so, the thesis contributes to advancing a behavioural geography of micromobility, situating satisfaction and wellbeing within broader processes of spatial negotiation, socio-technical adaptation, and urban transformation.

In conclusion. in light of these results and sum up, the thesis invites a more critical reflection on the widespread assumption that technological innovation alone can deliver more sustainable and inclusive urban environments. While the promotion of micromobility undoubtedly represents a necessary change in mobility planning, the results presented here warn against relying too much on technology as a universal remedy. As the case studies show, the introduction of new modes, however innovative, does not automatically reduce inequalities or displace unsustainable practices. On the contrary, it often reproduces existing exclusions and generates new forms of disparity, determined by ownership patterns, access infrastructures and social norms. Therefore, the promise of sustainability cannot be dissociated from issues of governance, spatial justice and user diversity. Rather than inflating expectations around the transformative power of micromobility, we must ground our ambitions in the complex realities of how these technologies are appropriated, resisted and experienced. So far, the gaps they were expected to close remain open.

# 7. Final reflection

## 7.1. Strengths and limitations

One of the main strengths of this dissertation lies in its multi-methodological approach. By combining both quantitative and qualitative methods, the thesis examines micromobility travel behaviour from the user's perspective. This methodological synergy enables an understanding of micromobility modes not only as relevant forms of transport influencing general urban mobility trends, but also as mobility practices shaped by the very environments and dynamics in which they unfold. Thanks to this methodological plurality, patterns have emerged that would likely have remained hidden if only one type of method had been applied. For instance, it has been possible not only to confirm that personal pleasure plays a more prominent role among private e-scooter users, a trend already visible in the quantitative data from Case Study 2, but also to understand how this personal pleasure seems to be articulated. Differences with bike-sharing users appear to be closely linked to the distinct hybrid character they both show, which allow e-scooters to be more easily integrated into diverse urban rhythms and combined with informal uses such as weaving through traffic, riding on sidewalks, or stopping spontaneously. These situated and adaptive uses, largely absent from shared bicycle narratives, shed light on how emotional and embodied experiences are shaped by the affordances of each mode. Without this layered methodological approach, such dynamics would likely have remained overlooked.

From a theoretical perspective, the thesis has incorporated approaches to travel satisfaction and wellbeing that move beyond static conceptions of the travel experience. By adopting a dynamic understanding of satisfaction, one that attends to shifting emotions and affective states throughout the trip, it becomes easier to observe how certain feelings, behaviours, or skills can offset other negative emotions or infrastructural shortcomings, contributing asymmetrically to the construction of wellbeing during travel. Opening up this line of inquiry and contributing to the broader debate on how satisfaction is generated, specifically in relation to emerging mobility modes, is considered one of the strengths of this dissertation.

This methodological plurality also allowed the analysis to adopt a multi-scalar logic. While the first article used the week as the primary unit of analysis, the remaining studies focused on the trip level. This shift in scale enabled, on the one hand, an initial general overview of how emerging modes are being deployed and how they coexist with traditional transport modes in a context marked by regulatory fragmentation. On the other hand, it brought the analysis closer to the street level, helping to clarify the dynamics and mobility decisions users make when navigating the city with these emerging modes.

At the same time, this research approach also entails a number of limitations. The rapid emergence and widespread adoption of micromobility modes under study caught public administrations somewhat off guard. At the time this dissertation was initiated, the main mobility surveys in Barcelona and its metropolitan area did not include disaggregated data on this type of modes. Although some differentiation has since been introduced, the Working Day Mobility Survey (EMEF), the primary tool used to monitor mobility patterns in the region, still lacks disaggregated information on several relevant micromobility modes. Against this backdrop, the thesis relies on an ad hoc survey designed and disseminated within the framework of the NEWMOB research project. While the sample quotas and parameters were aligned with the few official reports available on micromobility at the time of data collection, the use of a non-probabilistic sampling method requires that the results and their generalizability be interpreted with particular caution.

Moreover, while this dissertation provides insight into the environmental implications of micromobility through a behavioural lens (focusing on users' modal substitutions) it does not include a full life-cycle perspective. Specifically, the analysis centres on the consumption phase and self-reported modal shift, without accounting for the broader environmental impacts associated with vehicle production, operational logistics, or infrastructure maintenance. As highlighted in previous literature, including recent work by Felipe-Falgas et al. (2022) in Barcelona, Life Cycle Assessment (LCA) approaches show that shared micromobility services do not always lead to environmental gains. Their results suggest that shared e-bikes and e-mopeds may even increase greenhouse gas emissions, depending on how and where they are deployed, while only shared bikes and personal e-scooters consistently reduce emissions. Moreover, while some micromobility modes help reduce NOx emissions, they may increase particulate matter, though often outside the urban core. These findings reinforce the need to assess micromobility's environmental value not only based on user behaviour, but also by considering vehicle design, operational lifespan, and deployment strategies. Future research should aim to bridge these two perspectives, behavioural and life-cycle, to better evaluate the true sustainability potential of emerging transport modes.

Finally, while it has been argued that the use of mobile methodologies to study a relatively emergent urban phenomenon offers a more comprehensive understanding of its presence in public space, certain limitations remain. Logistical and methodological decisions, along with the researcher's positionality during the interviews and the participants' varying willingness to engage, could have been approached differently, potentially leading to alternative forms of interaction and insight. These limitations open up opportunities for future research that can overcome the shortcomings identified. The following section explores possible lines of research to advance in the study of micromobility

## 7.2. Future research

Once the strengths and limitations of this thesis have been outlined, it is worth identifying a number of future research directions that could deepen and nuance the understanding of the micromobility phenomenon. This section highlights several possibilities that may contribute to a more refined exploration of emerging urban mobility practices:

1. From a quantitative perspective, future research could benefit from expanding the analyses conducted in this dissertation by employing probabilistic sampling techniques. While the current findings provide robust insights based on well-defined quotas, probabilistic samples would enhance the representativeness of the results and allow for stronger generalisations, particularly when assessing population-level trends or differences across demographic groups.

2. Socioeconomic inequalities in micromobility use have been partially addressed in this thesis, particularly through the identification of differential adoption patterns across educational levels, place of residency and professional status. However, future research could strengthen this line of inquiry by incorporating more direct and granular income-based variables into survey instruments. While it is well known that collecting reliable income data poses methodological challenges, doing so would enable a more precise analysis of how economic resources shape both access to and experiences of micromobility, especially when comparing shared and private systems.

3. To apply this research strategy in other urban contexts, with a particular interest in those realities sharing comparable micromobility ecosystems and regulatory frameworks, such as Paris or Luxembourg. Translating the mixed methods approach developed in this thesis to these settings would allow for comparisons across contexts, which would help to identify which observed patterns are context-specific and which may be valid more generally in European urban settings. Furthermore, such comparative studies could shed light on how different governance models, infrastructure investments or cultural perceptions influence both behavioural adaptations and affective responses to micro-mobility. In this way, this line of research could contribute to a more generalisable understanding of the role of micro-mobility within different urban mobility regimes,

4. One promising avenue for future research lies in the further development and adaptation of mobile methods to study emerging transport modes. This thesis has demonstrated that techniques such as ride-along interviews and video observation can offer holistic insights into new urban mobilities, capturing not only behaviours but also embodied and affective dimensions of travel. The application of these methods has proven valuable for understanding the street-level dynamics of micromobility, but also reveals a broader methodological potential yet to be fully explored. Future research could extend these approaches to other cities, mobility modes, or populations, refining their design and opening critical debates about the epistemological, logistical, and ethical challenges that mobile methodologies entail.

## 7.3. Policy implications

In light of the findings presented in this thesis, it is essential to engage policymakers and urban planners in ensuring that the deployment and normalisation of micromobility modes are guided by sustainability principles, not only in behavioural terms, but also in relation to social equity and environmental impact. Based on this overarching premise, several specific recommendations are put forward. First, it is strongly recommended that the public administrations responsible for the Enquesta de Mobilitat en Dia Feiner (EMEF) incorporate a greater level of disaggregation in their data collection instruments, so that micromobility can be meaningfully studied and interpreted in ways that are statistically representative of the broader population. Without such data, urban mobility planning risks overlooking key trends and inequalities associated with these emerging modes. Second, it is imperative to actively promote a modal shift away from private motorised vehicles, particularly cars and motorbikes, towards micromobility. As long as micromobility use continues to primarily substitute already sustainable modes such as walking or public transport, its environmental impact will remain marginal. Only by reversing current substitution trends can micromobility live up to its purported role in decarbonising urban transport. Third, although the recent expansion of shared bike systems across the metropolitan area represents a promising step, the current design and implementation remain insufficient. A genuine metropolitan system requires a coordinated strategy among municipalities to ensure real, not symbolic, connectivity between first-ring towns and the city of Barcelona. Without such integration, shared micromobility will continue to operate in fragmented, city-bound pockets, limiting its potential. Fourth, and equally important, significant investment is required to improve infrastructure on multiple levels. First, micromobility users must be physically separated from motorised traffic: the perceived risk of sharing space with cars continues to be a major deterrent to adoption. Second, the continuity and connectivity of the cycling network must be strengthened. Fragmented or abruptly ending bike lanes reduce the usability and comfort of micromobility travel. Third, clearer signage and user-oriented wayfinding systems tailored to the perspective of micromobility users should be implemented. Such measures would enable safe and reliable access to new areas of the city that are currently perceived as unreachable or risky. Finally, attention must also be paid to the design and upkeep of micromobility infrastructure, particularly in the case of shared bikes. Malfunctioning stations, mechanical defects, and poor layout frequently discourage even regular users from continuing to use the system. Ensuring mechanical reliability, intuitive interfaces, and user-centred station design is vital not only to retain current users but also to attract new ones. Micromobility must become a competitive and trustworthy transport option, one that is not adopted out of ideological conviction, but because it constitutes a clear improvement in people's daily mobility choices.

# PART IV – REFERENCES AND ANEXES

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# 9. Annexes

## 9.1. Letters of co-authors

UAB
Universitat Autònoma
de Barcelona

Campus de Bellaterra,
Edifici B, Carrer de la Fortuna, s/n,
08193 Bellaterra,
Barcelona

**A qui correspongui,**

Nosaltres, els coautors signants de les publicacions titulades **"Shared bikes vs. private e-scooters. Understanding patterns of use and demand in a policy-constrained micromobility environment"**, **"Unpacking the docked bike-sharing experience. A bike-along study on the infrastructural constraints and determinants of everyday bike-sharing use"** i **"Affective geographies of e-scooter travel: Infrastructure, emotions, and adaptive strategies"** reconeixem que Oriol Roig Costa presentarà aquest treball com a part de la seva tesi doctoral.

A més, renunciem formalment a la possibilitat de presentar aquestes publicacions com a part de qualsevol altra tesi doctoral, ja sigui en el futur o en el passat.

Confirmem el nostre acord i suport a aquesta decisió mitjançant la nostra signatura a continuació.

Atentament,

MIRALLES GUASCH MARIA CARME - 39851421B

Signat digitalment per MIRALLES GUASCH MARIA CARME - 39851421B
Data: 2025.06.08 11:54:53 +02'00'

**Carme Miralles Guasch**

Universitat Autònoma de Barcelona

ORIOL MARQUET SARDA - DNI 46145311C

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Date: 2025.06.09 13:47:03 +02'00'

**Oriol Marquet Sardà**

Universitat Autònoma de Barcelona

UAB
Universitat Autònoma
de Barcelona

Campus de Bellaterra,
Edifici B, Carrer de la Fortuna, s/n,
08193 Bellaterra,
Barcelona

**To whom it may concern,**

We, the undersigned coauthors of the publication titled **"Understanding multimodal mobility patterns of micromobility users in urban environments: insights from Barcelona"**, acknowledge that Oriol Roig Costa will present this work as part of his doctoral thesis.

Furhermore, we formally renounce the possibility of submitting this publication as part of any other doctoral thesis in the future or past.

We confirm our agreement and support for this decision by signing below.

Sincerely,

Van Acker

**Veronique Van Acker**

Luxembourg Institute for Socioeconomic Research

ARRANZ LOPEZ ALDO - 72984701C

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**Aldo Arranz López**

Zaragoza Logistics Center

MIRALLES GUASCH MARIA CARME - 39851421B

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**Carme Miralles Guasch**

Universitat Autònoma de Barcelona

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**Oriol Marquet Sardà**

Universitat Autònoma de Barcelona

## 9.2. Supplementary materials

### 9.2.1. Interviews conducted per interviewer per day project NEWMOB

Table 15. Interviews conducted per interviewer per day project NEWMOB

| | September 2020 | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Interviewer | 14th | 15th | 16th | 17th | 18th | 21th | 22th | 23th | 28th | 29th | Total |
| 1 | 9 | 17 | 21 | 21 | 19 | 11 | 12 | 11 | 16 | 0 | 137 |
| 2 | 0 | 20 | 18 | 16 | 17 | 15 | 11 | 6 | 9 | 0 | 112 |
| 3 | 8 | 21 | 16 | 18 | 8 | 13 | 5 | 6 | 13 | 0 | 108 |
| 4 | 0 | 10 | 14 | 16 | 14 | 10 | 8 | 5 | 9 | 3 | 89 |
| 5 | 0 | 20 | 20 | 20 | 12 | 12 | 7 | 8 | 14 | 0 | 113 |
| 6 | 5 | 17 | 17 | 18 | 12 | 11 | 18 | 5 | 11 | 1 | 115 |
| 7 | 8 | 14 | 15 | 13 | 4 | 10 | 14 | 13 | 12 | 0 | 103 |
| 8 | 0 | 20 | 25 | 19 | 21 | 12 | 15 | 3 | 10 | 0 | 125 |
| Total | 30 | 139 | 146 | 141 | 107 | 94 | 90 | 57 | 94 | 4 | 902 |

Source: Own elaboration

### 9.2.2. Brief questionnaire pre- mobile interviews

1. Participant code:
2. Age:
3. Gender:
4. Micromobility mode:
5. Years of experience with the micromobility mode:
6. Trip purpose:
7. How do you normally feel during this trip?

| | -4 | -3 | -2 | -1 | 0 | 1 | 2 | 3 | 4 | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | |
| I feel time pressed | | | | | | | | | | I feel relaxed |
| I feel worried not to be in time | | | | | | | | | | I feel confident about arriving in time |
| I feel stressed | | | | | | | | | | I feel calmed |
| | | | | | | | | | | |
| I'm tired | | | | | | | | | | I'm alert |
| I'm bored | | | | | | | | | | I'm enthusiastic |
| I'm fed up | | | | | | | | | | I'm engaged |
| | | | | | | | | | | |
| Trip is the worst I can think of | | | | | | | | | | Trip is the best I can think of |
| Trip is low standard | | | | | | | | | | Trip is high standard |
| Trip works poorly | | | | | | | | | | Trip works well |

### 9.2.3. Bike-sharing system users' mobile interviews tracks

Map 6. Participant BSS02 trip


Source: own elaboration

Map 7. Participant BSS03 trip


Source: own elaboration

Map 8. Participant BSS04 trip


Source: own elaboration

Map 9. Participant BSS05 trip


Source: own elaboration

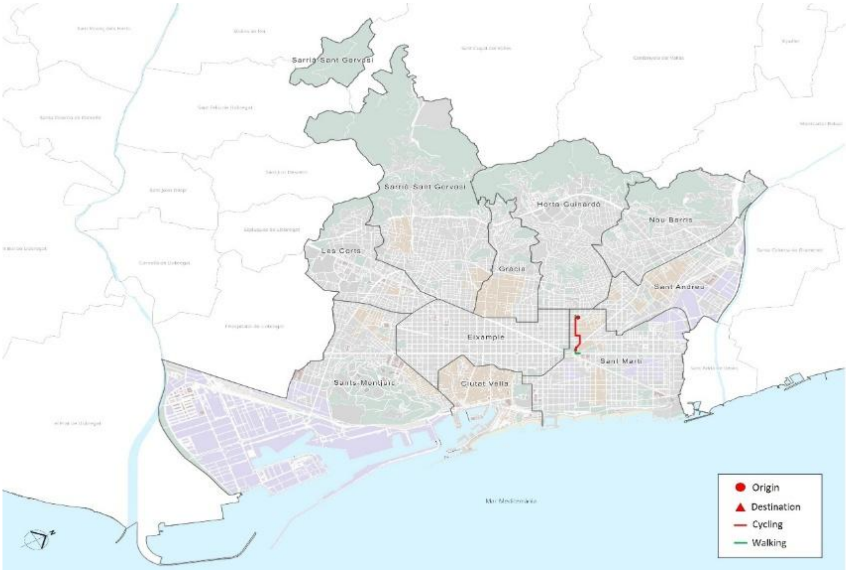
Map 10. Participant BSS06 trip


Source: own elaboration

Map 11. Participant BSS07 trip

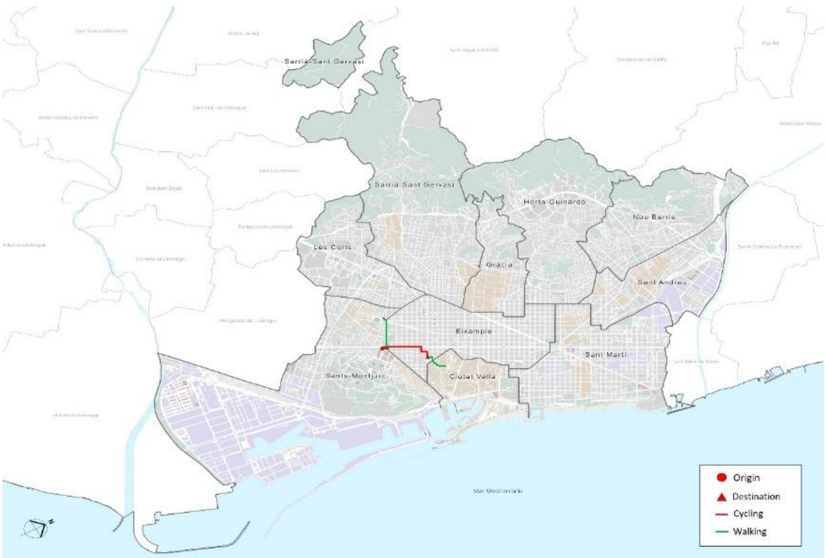

Source: own elaboration

Map 12. Participant BSS08 trip




Source: own elaboration

Map 13. Participant BSS09 trip




Source: own elaboration

Map 14. Participant BSS10 trip


Source: own elaboration

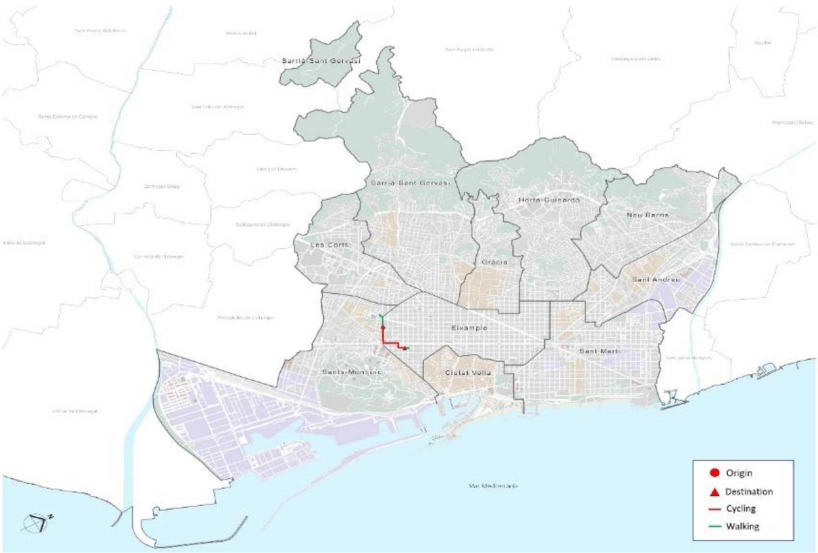
Map 15. Participant BSS11 trip


Source: own elaboration

Map 16. Participant BSS12 trip

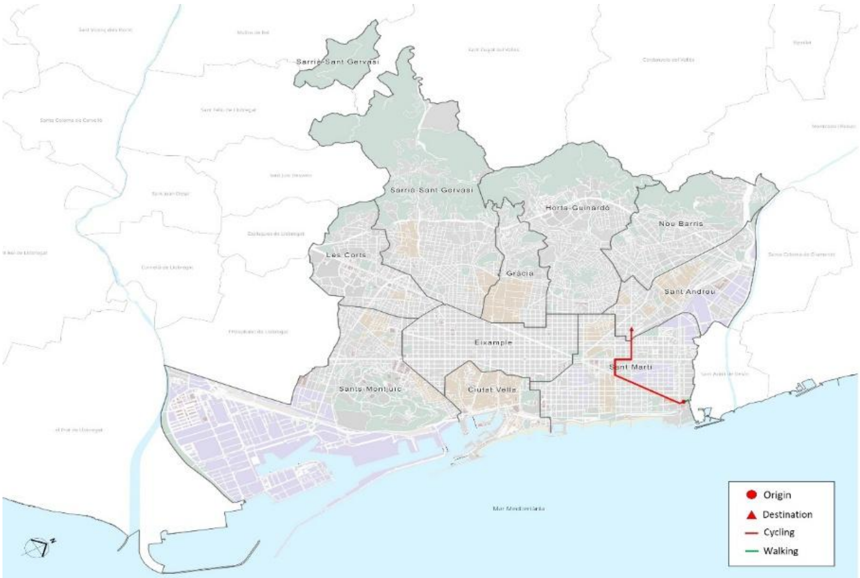

Source: own elaboration

Map 17. Participant BSS13 trip



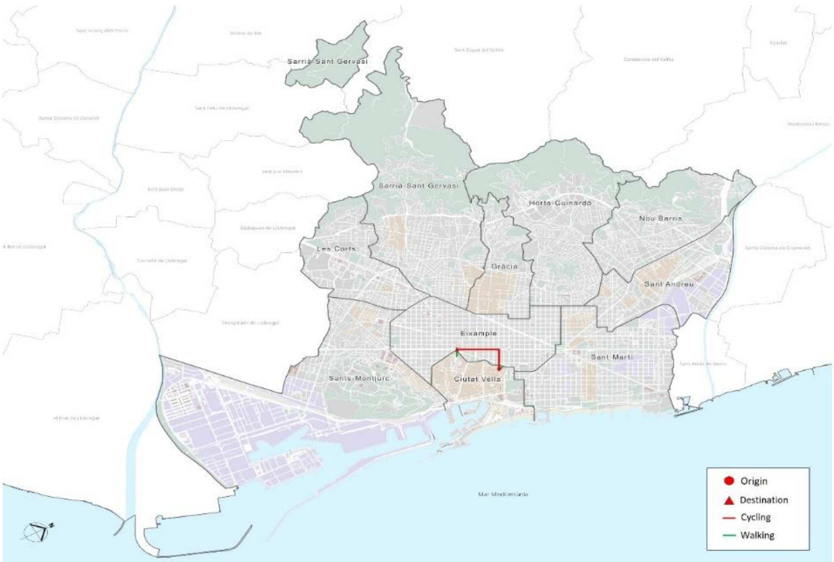

Source: own elaboration

Map 18. Participant BSS14 trip




Source: own elaboration

Map 19. Participant BSS15 trip




Source: own elaboration

Map 20. Participant BSS16 trip


Source: own elaboration

Map 21. Participant BSS17 trip

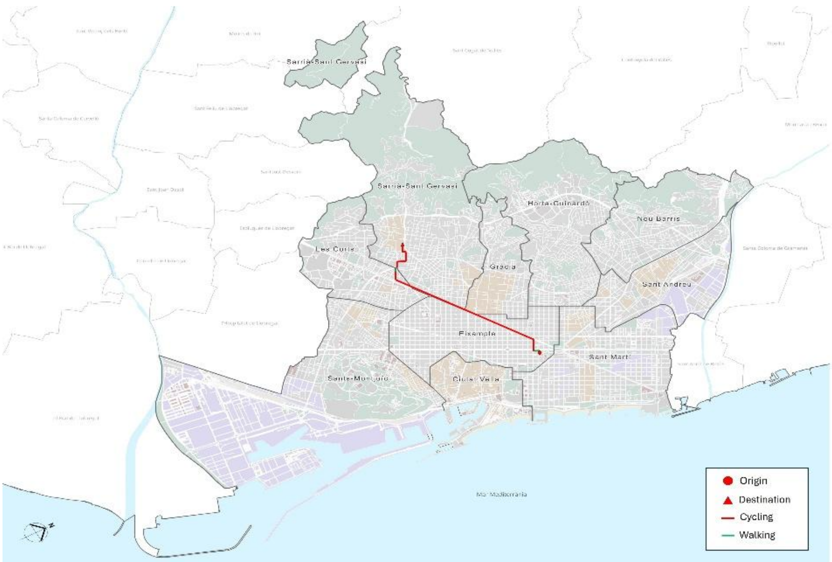

Source: own elaboration

### 9.2.4. E-scooter users' mobile interview tracks

Map 22. Participant ESC02 trip

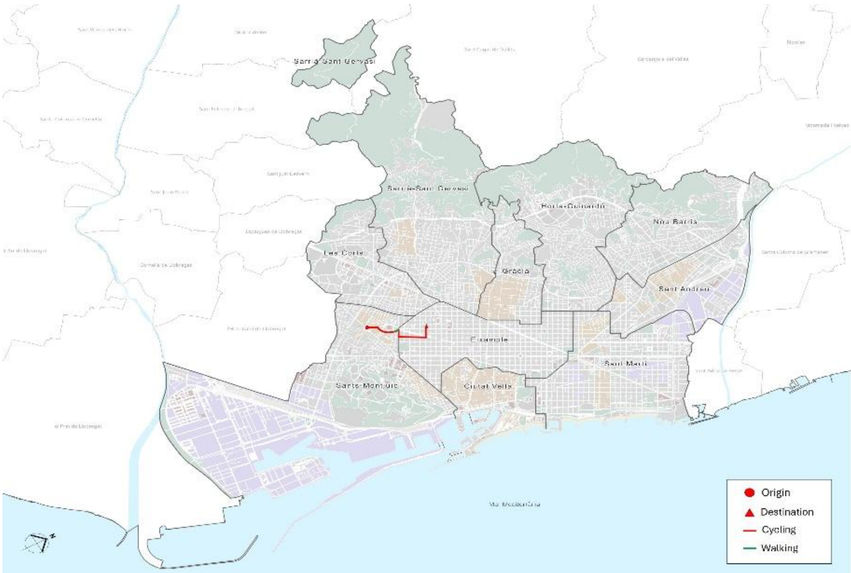

Source: own elaboration

Map 23. Participant ESC03 trip




Source: own elaboration

Map 24. Participant ESC04 trip

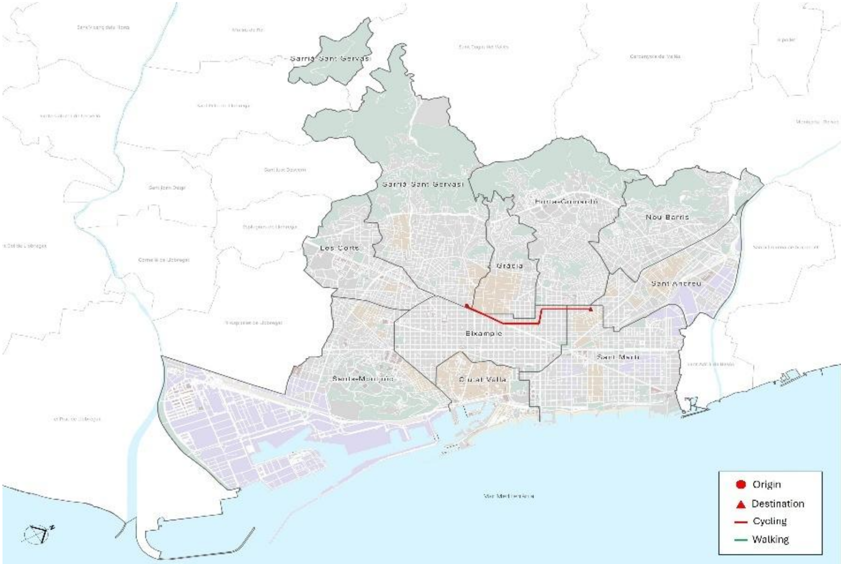



Source: own elaboration

Map 25. Participant ESC05 trip

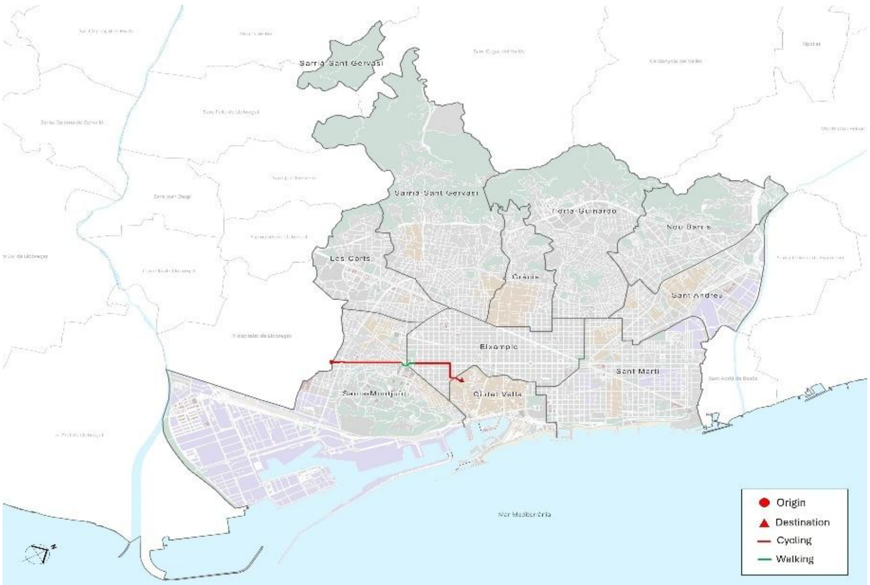

Source: own elaboration

Map 26. Participant ESC06 trip



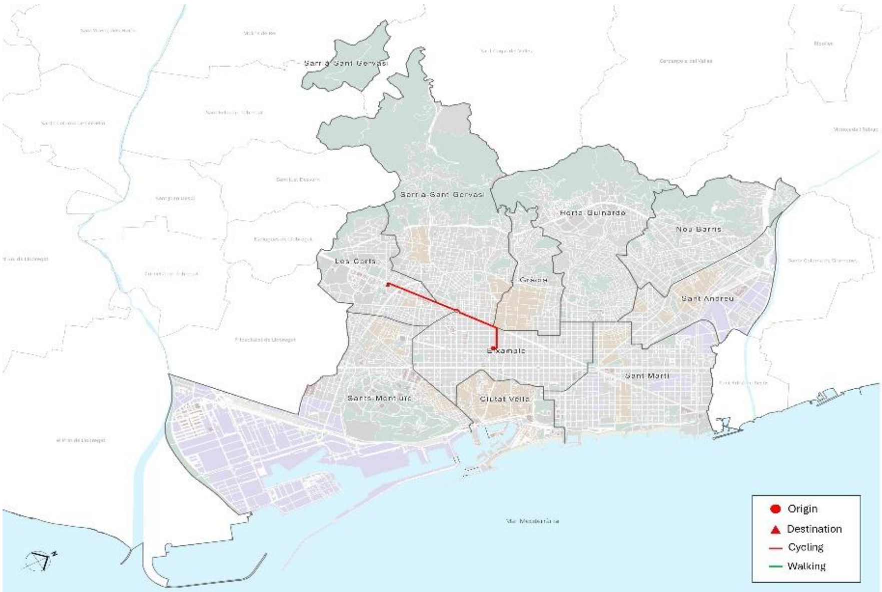

Source: own elaboration

Map 27. Participant ESC07 trip



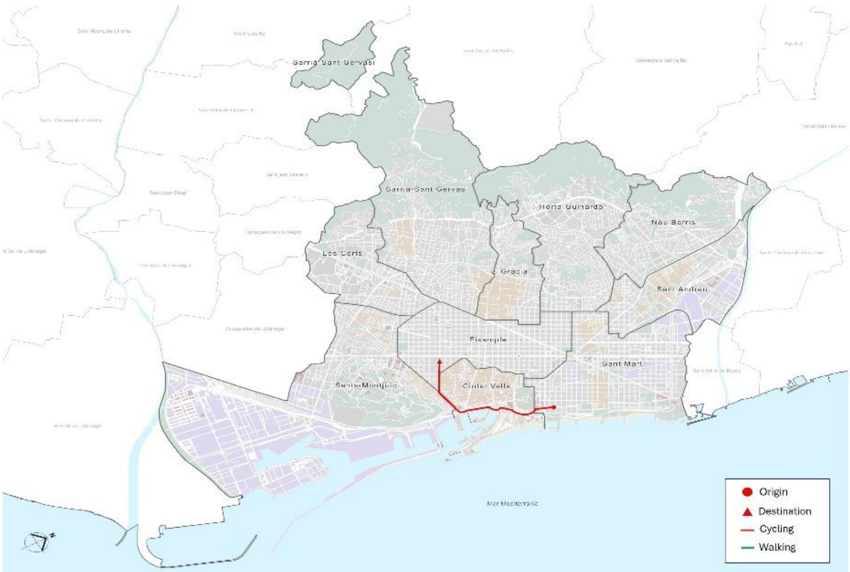

Source: own elaboration

Map 28. Participant ESC08 trip




Source: own elaboration

Map 29. Participant ESC09 trip

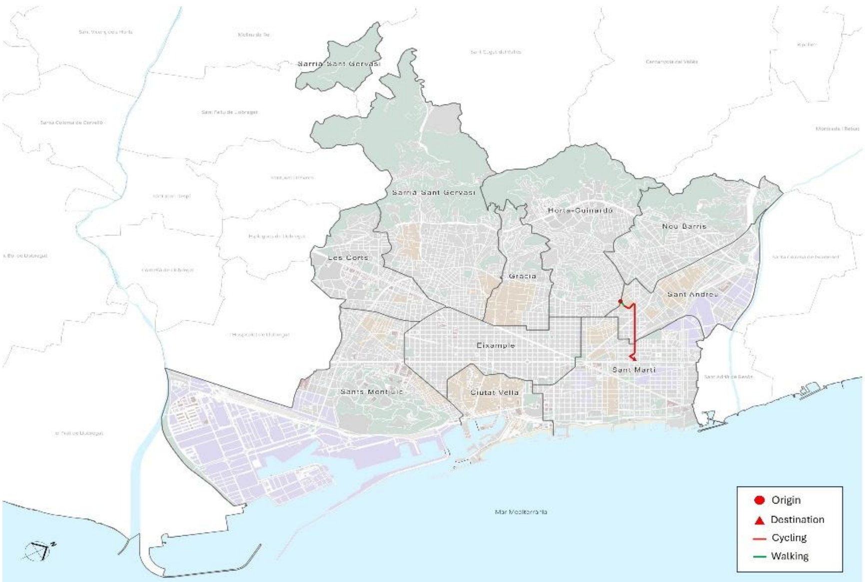



Source: own elaboration

Map 30. Participant ESC10 trip


Source: own elaboration

Map 31. Participant ESC11 trip




Source: own elaboration

Map 32. Participant ESC12 trip


Source: own elaboration

# 10. Thesis Outreach and Additional Activities

This annex compiles materials that have emerged indirectly from the thesis, including participation in national and international conferences, which have contributed to refining the content of the papers, talks and lectures related to the dissertation's subject matter, and research stays in foreign research centres. Additionally, while not included in the frame of this thesis, other academic publications related to the thesis' content have been published. These activities and contents are listed below:

## 10.1. Dissemination of the thesis results

### 10.1.1. Participation in national and international conferences related to the thesis

1. **Roig-Costa, O.** "Beyond the ride: A bike along study on infrastructural factors and determinants influencing the docked bike-sharing experience" at *AESOP Congress 2025. Planning as a transformative action in an age of planetary crisis.* Istanbul (Turkey), 7th – 11th July 2025.

2. **Roig-Costa, O.** "Uncovering Emotions and Strategies in E-Scooter Travel. A Video-Recorded Ride-Along Study" at *Royal Geographic Society Conference. Advancing geography and geographical learning*. London (United Kingdom), 27th – 30th August 2024.

3. **Roig-Costa, O.**, Van Lierop, D. "Assessing e-scooters' restriction on board public transport: A travel satisfaction longitudinal analysis" at *NECTAR Conference. Stakeholder involvement in transport: Who, why, how and with what impact?* Brussels (Belgium), 3rd – 5th July 2024.

4. **Roig-Costa, O.**, Marquet, O. "Understanding Mobility Streategies of Micromoility Users: Insights from Barcelona". *mobil.TUM 2024 – The Future of Mobility and Urban Space.* Munich (Germany), 10th – 12th April 2024.

5. **Roig-Costa, O.**, Marquet, O. "The Role of Infrastructure on E-Scooter Travel Satisfaction: A Ride-Along Methodology". *EUGEO, Geografia per al nostre futur comú.* Barcelona (Spain), 4th – 7th September 2023.

6. **Roig-Costa, O.**, Miralles-Guasch, C., Marquet, O. "La movilidad post-pandemia: el potencial de los nuevos vehículos de micromovilidad eléctrica y compartida" at *X Seminario Internacional de RIDEAL. Metrópolis pospandemia. Costos y desafíos.* Online Conference. 22nd – 24th November 2021.

7. **Roig-Costa, O.**, Miralles-Guasch, C., Marquet, O. "Micromobilitat a Barcelona. Un plantejament multi-metodològic" at *CICLOBCN21 - Pedaleando ciudades y territorios.* Barcelona (Spain), 5th – 8th October 2021.

### 10.1.2. Talks and presentations related to the thesis

1. Presentation **"Beyond the ride: A bike along study on environmental factors influencing the docked bike-sharing experience"** at "Seminari sobre Recerca Ciclista a BCN. Present i futur de la recerca ciclista a Barcelona", held at Institut de Ciència i Tecnologia Ambientals (ICTA), Universitat Autònoma de Barcelona, 15th November 2024

2. Online lecture **"Tendencias, perfiles de usuario y coexistencia con modos tradicionales"** at the online course "Micromovilidad: oportunidades y retos para la ciudad contemporánea" held by Grup d'Estudis en Mobilitat, Transport i Territori (GEMOTT), from 11th November to 15th November 2024

3. Online lecture **"Metodologías móviles para el estudio de la micromovilidad"** at the online course "Micromovilidad: oportunidades y retos para la ciudad contemporánea" held by Grup d'Estudis en Mobilitat, Transport i Territori (GEMOTT), from 15th November to 30th November 2023

4. Lecture **“Micromobility and Travel Behaviour. The use of mobile methods”**

   - Within the framework of the subject Qualitative Techniques for Territorial Planning of the Official Master’s Degree in Tourist Destination Management (Universitat Rovira i Virgili), 28th February 2025

   - Within the framework of the subject Qualitative Techniques for Territorial Planning of the Interuniversity Master's Degree in Territorial Planning, Governance and Leadership (Universitat Rovira i Virgili). 21st February 2024

5. Online lecture **“Other methodologies for the study of active mobility"** at online course “Curso cartografías urbanas para la movilidad activa”, held by Grup d’Estudis en Mobilitat, Transport i Territori (GEMOTT), 30th November 2023

6. Online lecture **“The use of qualitative tools for research: The case of Atlas.ti”** at Official Master’s Degree in Interdisciplinary Studies in Environmental, Economic and Social Sustainability (Institut de Ciència i Tecnologia Ambientals, Universitat Autònoma de Barcelona), 13th December 2021

## 10.2. Training

### 10.2.1. Attendance at conferences and seminars of interest

- Seminar **“Urban Space Interventions and Their Impact on Mobility and Health. Lessons from Tokyo and Barcelona”**, held by Institut de Ciència i Tecnologia (ICTA) on 8th November 2024, 10.00 – 13.00 CEST

- MdM Keynote Speaker Series 2024 **“Mobility and well-being: Five lessons learned from recent projects”**, held by Institut de Ciència i Tecnologia (ICTA) on 31st October 2024, 10.00 – 11.00 CEST

- Seminar **“Imagining [equitable] transport and [inclusive] city-making in the Global South”**, held by Universiteit Utrecht on 23rd April 2024, 13.00 – 18.00 CEST

- International Symposium **“Encounters in realm of urban change. Grounded views, global perspectives”**, held by IOS Platform for Open Cities from 5th to 7th June 2024

- Webinar **“Moving Towards Mobility Justice: How can we achieve fairness and inclusion in mobility?”**, held by AET Transport and Mobility Forum I Journal of Urban Mobility on 1st June 2023, 11.00 – 12.30 CEST

- Workshop **“Metropolis in motion. Barcelona and Santiago de Chile”** at the Institute of Environmental Science and Technology (ICTA-UAB) on 7th July 2022.

#### 10.2.2. Training activities

- Course **“Autoaprenentatge virtual sobre l’aplicatiu Zotero”** organized by Doctoral School of the UAB, 27th November 2024. 4 hours of dedication.

- Course **“Parlar en Públic”** thaught by Centre Ernest Lluch (CUIMP), 6th to 8th February 2024. 10 hours of dedication

- Course **“Research data: publish them openly and make the data management plan”**, organized by the UAB, 10th May 2023. 2 hours of dedication.

- Course **“Infografia 3.0 Comunicació visual de la recerca”** taught by Paco Sánchez Cano, from GESEM, the 11th, 13th, 18th and 20th April 2024. 8 hours of dedication.

- Course **“Dades de recerca: publicar-les en obert i fer el pla de gestió de dades”** taught by Cristina Azorín, Joana Ferrer Torrens i Marta Jordan Gili, from Servei de Biblioteques of the UAB, 18th May 2023.

- Virtual training in **“Psychosocial risks”**, between 15th December 2022 and 20th January 2023, organized by the UAB. 3 hours of dedication.

- Course **“Good Research Practices and Research Integrity at the UAB”**, on March 2022, organized by the Doctoral School of the UAB. 6 hours of dedication.

- Course in **“Quantitative Research Methods in Social Sciences: Program R”**, taught by Prof. Josep Rialp, on February 22, March 15 and 22, 2022, organized by the School of Doctorate in Tourism and the Department of Geography of the UAB. 10 hours of dedication.

- **“Institutional Mendeley Online Course”**, on 2021, organized by the Doctoral School of the Autonomous University of Barcelona (UAB). 4 hours of dedication.

### 10.2.3. Teaching activities

- Subject **“Metodologia del Planejament Urbà”**, at the *Official Master’s Degree in Territorial Studies and Planning* at the Universitat Autònoma de Barcelona
    - March 2025 (16 hours of teaching)
    - March 2024 (16 hours of teaching)
    - March 2023 (16 hours of teaching)
    - December 2022 (16 hours of teaching)

### 10.3. Research stays

- **Human Geography and Spatial Planning Department, Utrecht Universiteit**. Utrecht, The Netherlands. Supervision: Dr. Dea Van Lierop and Professor Dick Ettema. Dates: 05/04/2024 – 05/07/2024. Number of days: 92.

- **Urban Development and Mobility Department, Luxembourg Institute for Socioeconomic Research (LISER)**. Esch-Sur-Alzette, Luxembourg. Supervision: Dr. Veronique Van Acker. Dates: 21/09/2022 – 21/12/2022. Number of days: 91. Funding: FPI Short Stays Mobility Grant from the Ministry of Universities.

### 10.4. Other related publications

- **Roig-Costa, O.**, Miralles-Guasch, C., & Marquet, O. (2024). Disrupted intermodality: Examining adaptation strategies to public transport e-scooter bans in Barcelona. International Journal of Sustainable Transportation, 1-14. https://doi.org/10.1080/15568318.2024.2434881

- Nello-Deakin, S., Diaz, A. B., **Roig-Costa, O.**, Miralles- Guasch, C., & Marquet, O. (2024). Moving beyond COVID-19: Break or continuity in the urban mobility regime? Transportation Research Interdisciplinary Perspectives, 24, 101060. https://doi.org/10.1016/j.trip.2024.101060

- Cubells, J., Bretones, A., & **Roig-Costa, O**. (2023). Are E-Scooters a Threat to Active Travel? Journal of Healthy Eating and Active Living, 3(3), Article 3. https://doi.org/10.51250/jheal.v3i3.69

- **Roig-Costa, O.**, Gómez-Varo, E., Cubells, J., & Marquet, O. (2021). La movilidad post pandemia: perfiles y usos de la micromovilidad en Barcelona. Revista Transporte y Territorio, 25. https://doi.org/10.34096/rtt.i25.10958