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**How the COVID-19 changed the urban mobility ecosystem:
A perspective for new hybrid services**

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Master Thesis

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Abstract

The accelerated urban growth has brought environmental problems, contributing to the worsening of the climate crisis. Part of the responsibility for these environmental problems is due to the high level of carbon emissions generated by transport, which are increasingly demanded to transport people and goods, even more so in a digitalized world where e-commerce grows more and more. In mobility patterns have changed during the last two and a half years due to the COVID-19 pandemic. In the beginning, there was a reduction in mobility due to restrictions imposed by WHO, changes in the lifestyle of people who started to study and work from home, and an even stronger demand for electronic commerce to avoid the risk of contamination.

This study aims to understand the changes in mobility patterns in a focused way, and therefore, limited to the city of Porto, seeking to understand what were the main changes in terms of frequency and mobility choices, and what are the urban mobility trends for the mobility sector with a focus on sustainable urban mobility. In addition, it seeks to bring the service design lens to the analysis and visualization of the interactions of mobility services before and during the pandemic and propose solutions for a hybrid context characterized by cycles of restrictions and flexibilization of sanitary measures.

It can be divided into two main phases. The first was qualitative exploratory research involving mobility specialists, stakeholders from the city, the leading Porto's transport companies, and researchers, which provided information about mobility, sustainability, urban planning, and technology, then analyzed following the principles of thematic analysis. The second phase was the beginning of the ideation phase in the service design process, where the visualization of mobility services in the pre and during pandemic periods were explored, barriers added in result of sanitary measures were identified, as well as barriers that prevent the use of sustainable mobility.

Based on the analysis of the qualitative research, the inputs of the literature review and the barriers found in the visualization of mobility services, solutions were proposed for the identified barriers, signaling their benefits and the possible stakeholders involved in the strategies. Furthermore, with this study was possible to propose managerial implications for the development of new mobility services capable of adapting to the hybrid realities imposed by pandemic and sustainable initiatives. The findings, solutions and recommendations serve as a launching pad to implement new business models focused on sustainable urban mobility.

Keywords: Service, Service Design, Sustainability, Urban Mobility Services, COVID-19.

Resumo

O acelerado crescimento urbano trouxe problemas ambientais, que contribuem de forma negativa para a crise climática. Parte da responsabilidade desses problemas ambientais é devida aos altos níveis de emissões de carbono geradas pelos transportes, que têm sido necessários para transportar pessoas e bens, ainda mais neste mundo digital onde o comércio eletrónico cresce mais e mais. Os padrões de mobilidade têm mudado durante os últimos dois anos e meio devido à pandemia do COVID-19. No início, houve uma redução da mobilidade devido às restrições impostas pela OMS, mudanças no estilo de vida das pessoas que começaram a estudar e a trabalhar de casa e uma maior procura de comércio eletrónica para evitar o risco de contaminação.

Este estudo pretende perceber as alterações nos padrões de mobilidade, limitados à cidade do Porto, e quais as maiores alterações em termos de frequência e escolhas de mobilidade, e quais são as tendências de mobilidade urbano para o sector de mobilidade com foco na mobilidade urbana sustentável. Pretende ainda procurar trazer a visão do desenho de serviços para a análise e visualização das interações entre serviços de mobilidade antes e durante a pandemia e propor soluções para um contexto híbrido caracterizado por ciclos de restrições e flexibilização das medidas sanitárias.

Pode ser dividido em duas fases principais. A primeira é uma pesquisa exploratória qualitativa que envolve especialistas de mobilidade, stakeholders da cidade, a empresa de transporte líder na cidade do Porto e investigadores, que providenciaram informação sobre mobilidade, sustentabilidade, planeamento urbano e tecnologia; que foi analisada de acordo com os princípios de uma análise temática. A segunda fase foi o início de uma fase de ideação no processo de desenho de serviços, onde a visualização dos serviços de mobilidade antes e durante os períodos de pandemia foi explorada, as barreiras foram adicionadas como respostas às medidas sanitárias identificadas, como também às barreiras que inibem o uso de mobilidade sustentável.

Baseada na análise da investigação qualitativa, nos inputs da revisão de literatura e nas barreiras identificadas na visualização dos serviços de mobilidade; foram propostas soluções para as barreiras identificadas, sinalizando os seus benefícios e possíveis stakeholders envolvidos nas estratégias. Além disso, com este estudo foi possível propor implicações na gestão de desenvolvimento de novos serviços de mobilidade capazes de se adaptar a realidades híbridas impostas pela pandemia e pelas iniciativas sustentáveis. As conclusões, soluções e recomendações servem para alavancar a implementação de novos modelos de negócio focados em mobilidade urbana sustentável.

Palavras-chave: Serviço, Desenho de serviços, sustentabilidade, Mobilidade urbana sustentável, COVID-19.

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List of abbreviations

AI - Artificial Intelligence
AMP - Área Metropolitana do Porto
BS - Behavioral sciences
CC - Councilors
ECO-SD - ECO-Service Design
DRT - Demand-Responsive Transport
G-D- Good-Dominant Logic
IoT - Internet of Things
MaaS - Mobility as a Service
MTC - Mobility and technology companies
PDM - Plano Diretor Municipal do Porto
PR- Professors and Researchers
S-D - Service-Dominant Logic
SDGs - Sustainable Development Goals
SPSS - Smart Product Service System
STCP - Sociedade de Transportes Coletivos do Porto
TC - Transport companies

1 Introduction

The first chapter of this thesis addresses the context of the project, the motivations, and objectives of this Master's thesis. It briefly presents the project background and motivation, main research objectives and research questions that allow conducting the research, as well as the project report structure.

1.1 Project background

The future of world's population is urban. According to United Nations (2019), in 2050 is expected that the world will be two-thirds urban. The level of urbanization can vary in the different regions however the growth is common to all. In Europe, for instance almost three quarters of its population is expected to live in urban areas, which corresponds to approximately 85% (United Nations, 2019).

This accelerated growth movement has led to a series of sustainable problems that contribute to the climate crisis, generating the need for changes in the development model of cities and urban policies (Cavaco et al., 2015). Cities are contributing significantly to global greenhouse commissions, where one third of total emissions in major cities is generated by transport (OECD, 2020) as they are more accessible, and consequently people and goods are traveling more frequently, making the decarbonization process more difficult. (ITF, 2021). Despite the greater availability of transport, the urban sprawl and poor transport options led the use of the car to travel longer distances from residential areas to centers where the jobs and most essential services are located (OECD, 2018). These facts justify why the transport sector is one of the areas of economic activity in which technological and policy changes are most urgent to face climate change (Tikoudis et al., 2021) and reinforce the search for new alternatives to promote a more sustainable urban mobility system.

Besides the presented problems, the COVID-19 pandemic has brought a layer of complexity in cities. Due to its rapid spread, people spent most of their time at home trying to avoid the risk of viral spread (Dietz et al., 2020) and the world had to quickly adapt to these lifestyle changes and strict security measures (Tokazhanov et al., 2020). Regarding mobility, many studies have found that there is a significant reduction of human mobility, but significant changes in travel patterns (Monterde-I-Bort et al., 2022), like the increasing of adoption of active and soft modes and reduction in the use of public transportation (Lekić Glavan et al., 2022).

To analyze the existing mobility patterns in cities now and the perspectives for the future, it is necessary to restrict the object of study to factual data and the possibility of empirical research in a specific city. The city of Porto was chosen for being the second largest metropolitan area in Portugal and for featuring the intense urbanization process in the country through the growth of industrialization in coastal areas. Moreover, it concentrates more job offers and investments and has critical transport infrastructures for internal and external networks, such as ports, airports, and highways (Cavaco et al., 2015). With the existing networks that connect the city for the transport of goods and people, there is a clear opportunity for this investigation to understand the changes and trends of mobility in Porto city in a pandemic context.

1.2 Problem Description and Motivations

Following the topics mentioned in the previous section, the main problems and motivations of this master thesis are the investigation of the urban mobility services and their connection with the sustainability topic and COVID-19 consequences. In this section, it is explored the main motivations regarding the sustainability, then the problems to be considered due restriction and flexibility periods of the pandemic, and finally how the service design can be approached to analyze the set of problems presented in a holistic way.

In 2015, the United Nations Member States adopted the 2030 Agenda for Sustainable Development Goals (SDGs), consisting in a global action plan to seek sustainability in all countries. The agenda has 169 targets and indicators for monitoring, guided by 17 Sustainable Development Goals, managing the economic, environmental, and social dimensions (United Nations, 2016). Three of these SDGs are connected to this research:

- Industry, Innovation, and Infrastructure (Goal 9): Using technological progress to find solutions to economic and environmental challenges.
- Sustainable cities and communities (Goal 11): Making cities sustainable means creating business opportunities, safe and affordable housing, building resilient societies and economies, investing in public transport, creating green public spaces, and improving urban planning and management in participatory and inclusive ways.
- Climate Action (Goal 13): Adopting collective and urgent action to combat climate change and its impacts.

Portugal attaches great importance to the SDG9, aiming to support and develop initiatives for economic growth, social development, and combat climate change. In addition, the SDG13 is also one of the priorities, looking for improve energy efficiency and promote a planning and development of competitive low-carbon economy (National Report, 2017).

The COVID-19 pandemic made the SDGs more challenging to be achieved since some resources were redirected to combat the health crisis (Quatrini, 2021). Even with the relief of the COVID-19, the current world we live in still needs to acquire changes to become more resilient to possible upcoming disease outbreaks or lockdowns, and it introduces challenges for adaptation to a new reality (Tokazhanov et al., 2020). This fact sheds light on the need for urban mobility services to be more adaptable and adjusted according to the reality imposed, both by the pandemic, but also with climate issues.

With that said, the present study aims to adopt service design approach for the analysis of existing mobility services and how they can be adapted considering sustainability goals and the new measures that emerged due the pandemic. This perspective was selected firstly because of the growth of service sector presence in address transformative changes shaped by technological innovations, global pandemic, social upheaval, and climate crisis (Ostrom et al., 2021), and secondly due the significant role service design is having to improve existing services and implementing new ones, (Polaine et al., 2013) as well as, for your interdisciplinarity, holistic approach that helps to solve complex problems (Ostrom et al., 2010).

1.3 Research Objective and Questions

This research aim is to support CEiiA in the development of new mobility services capable of adapting according to the new hybrid realities imposed by pandemic and sustainable initiatives. To achieve that, the insights will be analyzed from qualitative research combined with topics from the literature review and using service design tools to demonstrate the relevant scenarios.

To address this challenge, the following research questions were identified:

What were the changes in mobility patterns in Porto during the COVID context?

Understand the current infrastructure of Porto city, how it is adapted for different mobility options, and what were the main changes in terms of frequency and mobility options choices.

What are the main urban mobility trends?

Identify of the emergent digital technologies and which of them have been applied in the mobility sector. This requires exploring solutions developed for the pandemic context, as well as, for different types of mobility services such as shared mobility, ride-hailing, public transportation, private cars, and micromobility.

How can service design methods and tools be applied to envisioning opportunities for sustainable hybrid mobility services?

The adoption of the holistic approach of service design can bring different perspectives through the involvement of multiple stakeholders. In addition, it aims to study the current citizen experience by mapping the interactions between citizens and mobility services of Porto, and envisioning opportunities for new service concepts in the future.

1.4 Study and Project Development at CEiiA

This dissertation has developed along with CEiiA, which is a Center of Engineering and Product Development and is one of the largest Research and Development investors in Portugal. This institution has existed since 1999, and it operates essentially in the areas of mobility, automotive, ocean and space, and aeronautics. Its daily mission is to be a global reference in research, design, manufacturing and testing of products and services for the mobility industries and establish Portugal as a reference for innovation and technology (CEiiA, 2015).

This investigation is collaborating with CoLAB Smart & Sustainable Living unit, where the main objective is to accelerate the transformation of cities into smart and sustainable urban ecosystems, promoting livability. CoLAB is structured in an interdisciplinary and multi-institutional way, having partnerships with universities, R&D centers, companies, start-ups, municipalities, social and cultural associations, and civil society. Its main focus is promoting co-creation and involvement of multiple actors during their experiments, both in developments and testing phases.

1.5 Report outline

This investigation work is structured as follows:

- The first chapter presents the project's context and the problem description.
- The second chapter is dedicated to the literature review, which brings up the reflection proposed on the research questions. The reviewed topics are understanding the current Porto's infrastructure in terms of mobility, the consequences of COVID-19 pandemic in the mobility sector and mobility patterns changes, and finally, what could be applied in emergent technologies to new service developments. The literature review also focuses on the concepts of service design principles and methods and how to use them to understand and design complex ecosystems context.

- The chapter 3 explains the research methodology, the selected methodology, how the data was collected and analyzed, and the methods used to materialize the insights.
- Then, the chapter 4 discusses the findings of the data analyzed and the adoption of the service design approach to visualize the main stakeholders that could directly or indirectly involve the future project developments. It also identifies service, infrastructure, technological and sanitary measures, and other barriers that could be overcome in future business models. In addition, it applies the insights visually in constructing citizens' journeys that considered the use of different types of transport throughout the pre and pandemic phases.
- To create opportunities, the next chapter - the fifth - presents the proposed solutions to address the barriers identified, their benefits and which stakeholders should be involved in developing new mobility services.
- Finally, chapter 6 describes the managerial implications to guide management decisions in developing new mobility business models.
- The last chapter wraps up the main conclusions and points for future research.

2 Literature Review

This chapter will cover the main topics necessary for the development of the study, serving as a theoretical basis, but also as complementary material for the analysis of the qualitative research results to be carried out in this project. The literature review will focus on collecting data and references from academic studies and reports from transport, health, and statistics institutions to understand the impacts of the COVID-19 pandemic on the experience of urban space and impacts on people's lifestyles, looking for correlating changes in the mobility pattern in Portugal, and with the means of transport available in the Porto metropolitan area, as well as the main initiatives for the future. In addition, it seeks to understand the fundamentals of service design and its application and gaps in sustainable services, and how to consider the design of services in complex systems. Finally, the chapter ends with a literature review of the tools adopted in this study, which will help to visualize and propose solutions for new business models in the mobility sector.

2.1 COVID-19 impacts in the urban cities

The COVID-19 pandemics had a significant impact on everyday city life, imposing lockdowns on entire cities and profound changes to mobility patterns. (ITF, 2021)

The first mandatory measures implemented were the closing of public buildings such as schools, libraries, offices, indoor markets, shopping centers, sports halls, museums, cinemas and theaters, churches, and others, since closed spaces, ventilation, occupancy rate and sanitation were recognized as critical parameters to prevent the spread of the virus (Glavan et al., 2022). There were also restrictions for the circulation in open spaces such as beaches, parks, and green areas in the first phases, which generated controversies about how these spaces could be a significant risk factor while they could bring physical and mental benefits (Geng et al., 2021).

Due the restrictions to use public space, a numerous of negative social and economic side consequences raised (Chakraborty et al., 2020), however, even temporarily, the general ecological state of the urban environment benefited from this situation, as there was an improvement in air quality and surface water quality, while urban noise and the heat island effect were reduced (Cheval et al., 2020). Some negative environmental impacts can be referred more to the pollution caused by the disposal of sanitary materials such as masks and gloves, and to the accumulation of waste and reduction of recycling (Zambrano-Monserrate et al., 2020).

The COVID-19 crisis has profoundly changed people's view of their own homes. This experience has changed housing preferences, such as more space, even if it means living further away from offices and consumer services (Ahrend et al., 2022). There was an acceleration in digitalization, where people who left the city were able to work remotely thanks to the internet (United Nations, 2020). They could make online shopping, access healthcare using telemedicine, stay in touch with the family via online meetings (Frumkin, 2021). Google searches for delivery options almost doubled in some countries. Nevertheless, it is important to analyze that not all groups of individuals, usually those related to low economic and social conditions, unequal access to education, aging, or those who lived in rural-urban divides, benefited from, or had access to online shopping. This is due to multiple reasons from low connectivity, lack of digital skills, and security and privacy concerns, and lack of access to online payment mechanisms. This led to several government initiatives to overcome these problems but still left many gaps for the people mentioned to have more access (OECD, 2020; United Nations, 2020).

Mobility as well as the public transportation usage were significantly reduced. The applied reduction in the capacity of public transport vehicles, as well as the initiative to avoid the crowd, had two impacts on city streets: the number of pedestrians and cyclists and of private vehicles increased (Eisenmann et al., 2021). To increase the adoption of bicycles and walking as a mode of transport, some cities have built as public policies the extension of cycle lanes and pedestrian zones. For instance, Bogotá increased the number of bike lanes using traffic cones (Miketa et al., 2020) and has doubled the percentage of cyclists in the city (Medina et al., 2020), New York used parts of its road network to allow cyclists to commute in the city (Nikitas et al., 2021), Paris has built 50 kilometers of temporary bike lanes by taking space from motor vehicles (Medina et al., 2020).

Even with the avoidance of people in using public transport, the public transport operators adapted operations to maintain services during the crisis. In many cities, buses and trains continued operating with reduced maximum capacity to allow physical distancing. They quickly installed plastic barriers to ensure separation and protection of bus drivers and other transport personnel. Operators suspended the on-board sale of tickets and front-door boarding to reduce exposure (ITF, 2021). These were important initiatives for public-facing workers to be able to commute to work (Florida et al., 2021).

It must be understood that COVID-19 has not been eradicated in the world. According to the latest WHO Weekly Epidemiological Update, the number of weekly cases has increased worldwide for the third consecutive week, following a downward trend since the last peak in March 2022 (WHO, 2022). While vaccines have helped save millions of lives in this pandemic, the ever-evolving virus has spread so far that it may linger (Joi, 2021). There are some lessons learnt from the previous waves that we should be reviewed and some assumptions of what could work in the future based in the recent experiences. For instance, the policy of restricting movement in parks and green spaces, which in the first lockdown was established in some countries, but which some studies claim low risk of contagion and improvement in physical and mental health. (Slater et al., 2020). Investment in bike lanes is necessary for the period of relaxation and restriction of the pandemic, as they can provide viable transport solutions without agglomeration, and traffic calming measures can complement the more successful circulation of bicycles (Nikitas et al. 2021).

Liu et al. (2022) recommends that the safety on transportation systems can increase if the recommended social distancing of at least 1 meter is adopted, combined with the implementation of air-ventilation and purification to increase indoor ventilation and filtration, the use of mobile applications to help monitoring mobility patterns and crowds on different routes, and the cleaning surfaces made by transport operators in the daily basis.

With all the lessons learned and evidence that we have from studies on how to stay safe from COVID-19, there is a need to understand how to deal with everyday life and with periods of restrictions and flexibility and how sustainable mobility in city can adapt to these events.

2.2 Mobility patterns during COVID-19 in Portugal

Portuguese population reacted quickly, adopting social distancing, and changing their mobility pattern, even before the government decreed the first restrictive measures (Tamagusko et al., 2020). This awareness, combined with the high vaccination rate of the population, was crucial to making the fourth wave more controlled. However, with the uncertainty regarding virus mutations, the physical distancing measures, testing, and isolation measures remained to control the successive waves (OECD, 2021).

Some data confirm that the restrictive measures caused by the COVID-19 pandemic impacted the use of different means of transport in Portugal. For instance, in 2020, passenger transport showed, in general, strongly negative variations in terms of the number of passengers transported. For instance, Metro do Porto transported 39.4 million passengers in 2020, showing a decrease of 44.7%. In 2020, 102.2 million passengers were transported by train, corresponding to a decrease of 41.7% (INE, I. P., 2021).

INE (2021) report shows that because of the lower circulation of vehicles on Portuguese roads, a 30-day accident data in Portugal provided by the ANSR revealed a 25.6% reduction in the number of accidents. The total number of victims also dropped sharply, corresponding to -28.2%, both in terms of deaths and injuries.

As presented in figure 1, despite the decrease in the use of public transport, there has been a recovery in use in recent times. The Google COVID-19 Community Mobility Report (2022), that shows data collected from mobile devices to quantify people's movement during the pandemic, presents a growing curve in the use of transport hubs such as subway, bus, and train stations. In Porto, between the end of April and the beginning of June, there was a growth of 12% compared to baseline.



Figure 1 - Mobility changes for the transit stations (Google LLC, 2022).

Cycling becomes a particularly attractive alternative within the COVID-19 context, characterized by the geographical limitations on travelling, where short trips at the local level have gained a new relevance (de Haas et al., 2020). This is in line with the study made in Lisbon by Costa et al. (2022), which shows that lockdown made individuals think about the bicycle as a viable transport mode. This same study points out that the increase must combine the increase in cycling frequency with adequate infrastructure and connectivity to better meet cyclists' needs and prevent them from returning to motorized modes.

Among the needs that could fulfill the needs of cyclists, especially those who do not have their own bicycles, is the coverage and quality of bike systems. This is said because considering another study also carried out in Lisbon by Teixeira et al. (2021) the main motivations to stop using bike sharing were linked to the shortage of shared bikes, lack of stations near their destinations or home, and poor condition of the bikes were the main reasons for quitting the system. Other important requirements from bike users are protected infrastructure such as bike lanes and paths and the presence of parking facilities to increase the adoption and satisfaction rate of this transport mode (Handy et al., 2014).

Regarding this, the Portuguese government has developed a National Strategy for Bicycling and Active Mobility, which aims to increase the number of bike lanes in Portugal to 6 500 km in 2023 and 10 to 000 km in 2030 and encourage a shift from private vehicles to public transport, and active and shared mobility (IEA, 2021). In addition, the government introduced

subsidies for the purchase of new electric bicycles and regular bicycles, including cargo bikes (Boost, 2020).

The Porto City Council also proposed initiatives in order to rescue public space, focusing on pedestrian areas and on expanding the network of cycle paths, as well as better integration with intercity routes with a possible integration between public transport and micromobility, and calming traffic that allow a better coexistence in the use of public space (Baganha, 2021).

It is clear that there are many opportunities for alternative and sustainable transport. The government already has initiatives to be implemented and investigated in the future in terms of efficiency. Even with all the initiatives, one of the challenges to be faced is the resistance to the adoption of alternative modes of transport and the return to public transport. This research aims to investigate, by combining the results of the qualitative study with the application of service design tools, what would be the recommendations to deal with the relationship between implementation and validation to become a participatory cycle with the aim of better continuity.

2.3 Porto's mobility options and infrastructure

Infrastructure

Porto is the second important town in Portugal, and it is situated inside a metropolitan area which comprises 1 737 395 inhabitants (INE, 2021), located in the northwest coast of Iberian Peninsula. The Portuguese urbanization has mostly occurred along the coastal areas and consequently the distribution of the population is asymmetric, with a dynamic coastal region, and dual as it is mainly positioned around the two regions of demographic polarization of Lisbon and Porto. (Cavaco et al., 2015)

In terms of urban rail infrastructure, Metro do Porto S.A. (2020) has 66.7 km of extension, and its fleet consists of trains powered by electricity, so there are no emissions of greenhouse gases directly associated to traction. However, indirect emissions are a reality, since part of the electrical energy used for the vehicle operation is a result of energy consumption of non-renewable origin present in the energy mix Portuguese. indirect emissions resulting from energy consumption by Metro vehicles amounted to an estimated total of 13.5 thousand tons of CO₂. Metro do Porto's activity generates savings considerable emissions. This savings is determined considering the alternative use to individual, collective motorized transport (Metro do Porto S.A., 2020).

Regarding Comboios de Portugal, the main railway company in Portugal, its infrastructure covers 336,050 kilometers long, and from an environmental point of view at national level, it has low emissions per passenger/km, representing 25.8 g CO₂e. (CP, 2020)

In road transport, focusing more on public transport such as buses, the AMP Institution (Porto Metropolitan Area) is responsible for matters leading to transport policy and its regulation. There are 17 municipalities, 29 operators and 725 bus lines distributed throughout Porto. (AMP, 2021). One of the most relevant transport operators is STCP (Sociedade de Transportes Coletivos do Porto), and the company has invested in the decarbonization of its fleet. As of today, STCP passengers are driven in 420 buses: 79% run on natural gas, 5% on electricity, and only 16% on diesel. The company acquired 3 more fully electrically powered buses, which will allow the reduction of 441 tons of carbon dioxide emissions per year (Porto, 2021).

As presented in the figure 2, the current cycling network is about 35 km long and along the route there are places for bicycle parking. It is intended to reach 54 km and ensure the connection between housing areas and facilities such as universities and schools (Câmara

Municipal do Porto, n.d.). There are also places to park bicycles in 5 metro stations (Metro do Porto, 2022) and 13 train stations (CP, 2022).

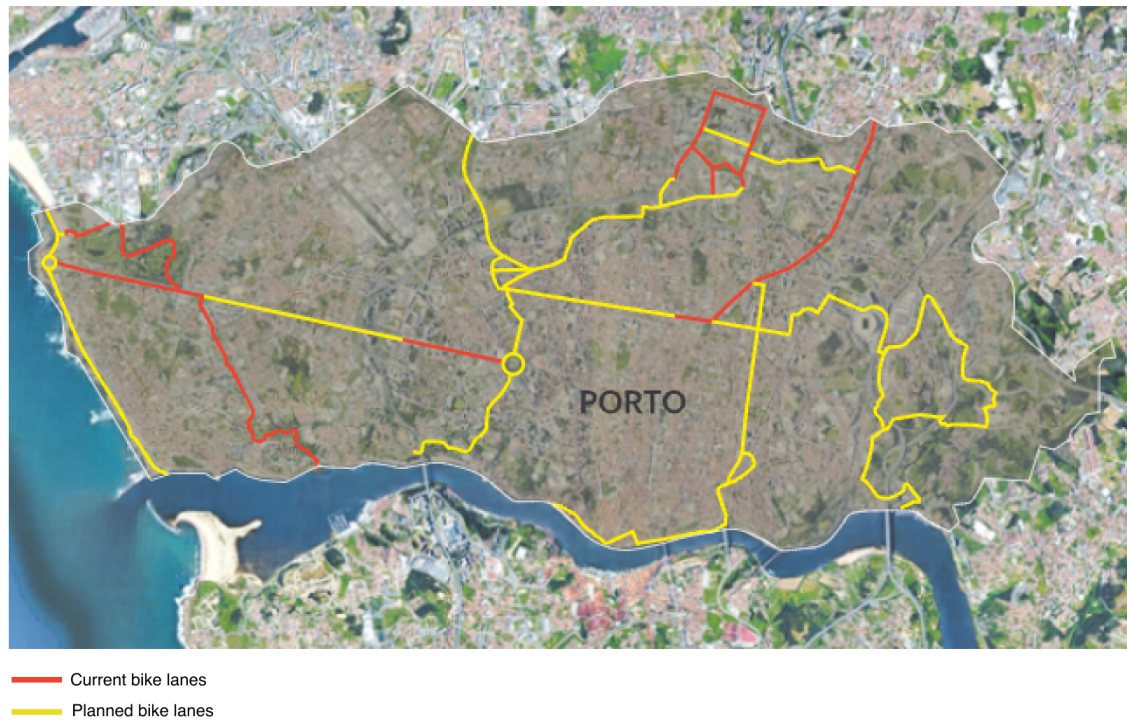


Figure 2 - Current and planned bike lanes in Porto's city (Coentrão & Pimenta, 2020).

Mobility options

Currently, mobility options in the Porto metropolitan area are divided into the following options: Air, Cycling, Rail, River, Seafarers, Road, and Electric (AMP, 2021). In Figure 3 only the modes of travel on the ground of the metropolitan area are considered, and these are divided at the sharing level and present the individual transport modes.

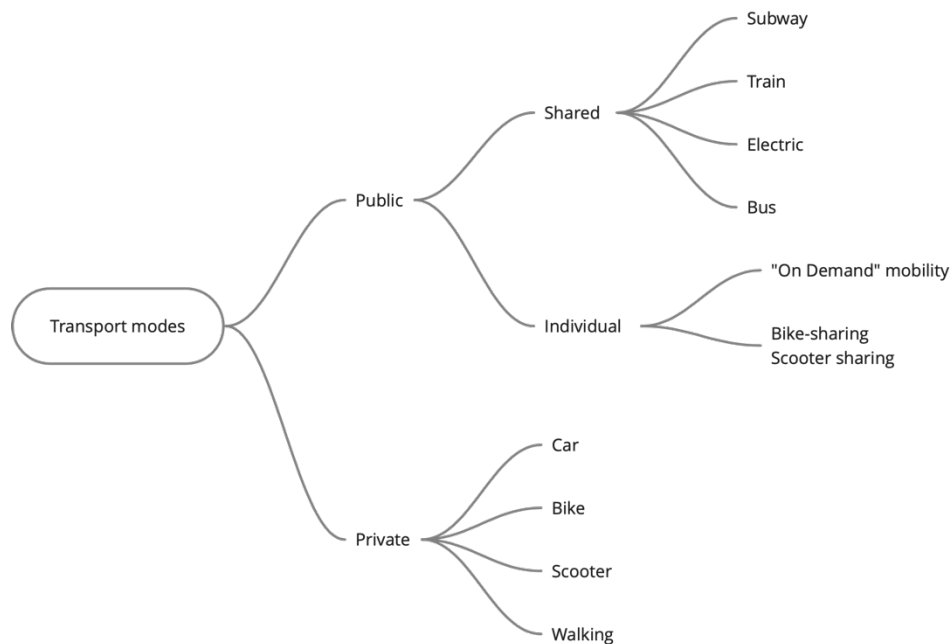


Figure 3 - Mobility options in Porto (Câmara Municipal do Porto, n.d.).

Following, we present the main transport types and the companies responsible for providing their services with a brief description to have a comparative study of how the services are provided and accessed by citizens.

- Public shared mobility services

The rail transport is provided by Metro do Porto and Comboios de Portugal.

Metro do Porto has a network of 6 lines with 82 stations, 24 of which are integrated with other means of transport for suburban cities.

Comboios de Portugal business area comprises a rail network with 5 axes. In the city of Porto, there are three stations that allow connections within the city, which establish the connection with the Porto metro network and with the bus network. The company also makes connections from Porto to various destinations abroad and in the country.

Although there are 29 road operators, STCP provides intercity public passenger transport services covering the Porto Metropolitan Area. It has 58 lines in its daytime network and 11 lines operating in the dawn network. However, the service provided by these operators does not allow travel to and from the interior of the city of Porto.

Under STCP's administration there are also 3 old tram lines in the city of Porto.

All these services can be accessed through the Andante intermodal transport ticket, where they can be loaded through the Anda app or through one of the sales outlets present in the train and metro stations.

- Public individual mobility services

For on-demand services, in the public sphere there are Taxis, which offer three types of services: the price counted by the taximeter, service by the kilometer, and service by the hour, which consists of the time of use of the vehicle. This service can be requested via telephone or at fixed taxi stops throughout the city. The payment method may vary, being possible to pay with cash or with credit card.

Some private companies also offer this service such as Uber, FreeNow, e Bolt. It's possible to access their services through their own apps and the payment is made through the registered credit card.

The same logic is applied to shared micromobility services. These services cover diversified transport modes, such as station-based bike sharing and dockless e-scooter sharing (Shaheen et al., 2019). The private companies that provide these services in Porto are Bolt, Bird and FreeNow, that are accessed and paid exclusively through their respective apps.

Although public shared mobility services are integrated both in their physical form and in their tariff integration, bike-sharing, scooter sharing and individual mobility services have their own access channel, whether through applications or other means, and your own payment methods. There is a clear opportunity to connect these modes of transport so that they can be easily found and used according to the citizen's needs and demands. Some places in Portugal are already solving this problem. For example, the municipality of Cascais developed MobiCascais, which is Cascais' integrated sustainable mobility management system, with the aim of offering a diversified and flexible set of mobility solutions, integrating public transport with smooth mobility solutions.

However, there is still a lack of projects like this fully implemented in the Porto metropolitan area, thus reinforcing the opportunity for the development of this type of business model.

2.4 Urban mobility trends

The car has established itself as one of the main possibilities for mobility, closely associated with commerce and social class advancement (Moreno et al., 2021). As a result, cities have been shaping the dynamics of urban planning, generating urban sprawl (Brown et al., 2009), negative impacts on biodiversity, quality of life, and mental health associated with increased traffic congestion (Gössling, 2020).

Today, we need to deal with the legacy of car-dependent urban planning, which makes visible social and economic inequalities, and has become an unsustainable practice (Newman et al., 2017). With the advancement of these reflections, the concept of mobility has been undergoing changes all over the world. According to the European Commission's long-term strategy vision (2018), cities need a reform of spatial planning, with the inclusion of green spaces and embracing the clean, safe, and connected mobility in an adequate and intelligent infrastructure that guarantees interconnection.

Related to these strategies, Tsavachidis and Petit (2022) stated that the future of urban mobility will be characterized by multimodal offerings of active, clean, shared and partially automated modes, including public transport.

Paiva et al. (2021) associated the future of mobility with the smart mobility concept and underlie key concepts that will be part of smart mobility in the coming years: on the one hand the transport of goods related to the robotization of delivery operations, directly impacting how store providers work, and demanding technologies such as Internet of Things (IoT), Bigdata and Artificial Intelligence (AI). On the other hand, in the transport of people, trends are evolving towards Mobility as a Service (MaaS), consisting in the reduction of the number of private vehicles that will be replaced by electric, shared, lighter and smaller vehicles with autonomous driving. A McKinsey (2021) report emphasizes that shared mobility is expected according to expand in coming years at an annual growth rate of over 20% through 2030.

Shared mobility can be defined as an innovative transportation strategy that enables users to have access to shared vehicles such as cars, bicycles, scooters, vans when required, and can increase multimodality, and reduce car ownership (Machado et al., 2018).

Shared mobility solutions can benefit the environment while also addressing societal issues such as fewer trips, mode shift, distance reduction, and reduce needs for parking slots. (Cohen and Kietzmann, 2014). As a result, the impact of shared mobility on transportation planning from the standpoint of sustainability and urban governance must be thoroughly considered. In recent years, shared mobility has grown in popularity and support, and there is a common understanding that by encouraging the use of newer and cleaner vehicles, as well as the wider use of sustainable modes of transportation, shared mobility can address several sustainability challenges, including air pollution (Akyelken et al., 2018).

Despite shared mobility services have potential to eliminate, on average, 6.3% of passenger transport emissions, it plays a complementary, rather than central, role in efforts to reach carbon neutrality. This means that it cannot be considered a stand-alone strategy for decarbonizing urban transport, rather it is complementary, integrating policies that seek to raise awareness of the private cost of using a private car versus its social cost, and subsidizing shared mobility so that the implementation is successful, facilitating the abandonment of car use (Tikoudis et al., 2021).

In terms of smart mobility, Debnath et al. (2014) performed a benchmarking of smart transport cities and found many promising initiatives that could be considered in the future, such as real-

time transit information, information on parking spaces, tracking of public and emergency vehicles en-route and at terminals/stations, helping to improve accessibility, reduce travel time, and enhanced efficiency of transit operations.

Valença et al. (2021) presents the main challenges and opportunities to implement a dynamic road space allocation using big data and data-driven approach, and how these technologies can help to plan the urban space for to more sustainable transport modes in many cities worldwide. Despite these technologies are established in cities like New York, Osaka or Berlin, there are still important steps to be developed in Portugal, since there is still a lack of available data to start developing these services (Silva et al., 2021).

This lack of data can be a key issue to be addressed in Portugal when we refer to Mobility as a Service, which is also one of the most relevant urban mobility trends. New transportation services and technologies, such as autonomous cars, have been closely linked to the *as a service* concept, which means that the mobility is no longer consumed as an asset, but rather accessed on demand (Wong et al., 2020).

According to MaaS Alliance EU (2022) Mobility as a Service combines various modes of transportation and transportation-related services into a single, all-inclusive, on-demand mobility service. The main issues addressed by MaaS are to suit the purpose of the trip, distance, and its limits. They include aspects of interoperability, which include standardization and inclusion of interfaces for open data, across different modes and media, and for diverse user-centric applications. And finally, sustainability in terms of environmental impact, if it is economically viable, socially acceptable, and inclusive, and improved land use and planning (Giesecke et al., 2016).

The automotive industry is an industry leader in the development of “smart factories”, adopting a variety of Industry 4.0 technologies such as Internet-connected robotics, data analytics and high-performance computing. For instance, they are developing automated vehicles to increase efficiency of warehouse operations and creating new business models related to on-demand mobility services (Paunov et al., 2019). There are studies on AV in urban areas, but without concrete conclusions. The hypotheses raised are that these vehicles reduce the cost of travel, but at the same time, driverless individually owned vehicles may increase traffic when unoccupied and their use in congested urban areas may need to be regulated (Metz, 2018).

2.5 Service design

Service Design is as a human-centered, holistic approach focused on the creating services, improving new ones (Blomkvist et al., 2010), and is characterized by a multidisciplinary character by incorporating multiple contributions from services marketing, operations, and information technology (Patrício and Fisk, 2013).

This holistic approach allows service design to orchestrate service elements such as the physical environment, people, and service delivery process to help customers co-create their desired experiences (J. Teixeira et al., 2012), as well as clues and interactions that together create holistic service experiences for customers, clients, employees, business partners, or citizens (Ostrom et al., 2010).

It is applied in several industries, and therefore, adapting to a specific discipline (Joly et al., 2019). It can be associated with process design (Kimbell, 2011), understanding customer experiences (Zomerdijs et al., 2010), and generating innovative ideas through the design thinking process (Ostrom et al. 2010). Its scope can vary, however, all of them integrate design-

based approaches, methods, and tools (Patrício et al., 2013) and follow generic stages including exploration, ideation, and evaluation (Patrício et al., 2018).

In order to bring some general idea about service design approach, Stickdorn et al. (2018) revisited and highlighted six principles that better characterize it:

- Human-centered: is not only focus on the end-user but all the actors the participate on the service system.
- Collaborative: which means that multidisciplinary stakeholders with a different background and functions should be engaged in the service design process.
- Iterative: meaning that the development of a new service should be adaptable and experimental and should be available for change during implementation.
- Sequential: The service design should be visualized and orchestrated as a sequence of interrelated actions.
- Real: It needs to be researched, bringing tangible and intangible values, and representing them physically.
- Holistic: And as already mentioned, it must be holistic, which means that services should be sustained in delivering value to all stakeholders through the entire service.

There is a significant part of the literature dedicated to showing case studies investigating, analyzing, and evaluating the application of methods and tools in service design (Yu and Sangiorgi, 2014). These tools are used to capture the demands of the project, as well as, the problems, needs of the business and customers, transforming them into design opportunities (Stickdorn and Schneider, 2011).

However, it's important to highlight that service design is not a phase in a new service development (Yu and Sangiorgi, 2014), but a powerful approach than can break free from ongoing reproductions of existing institutionalized social structures. (Vink et al., 2019)

Based on this vision, it can be adapted better to the drastic changes in service sector, which in addition to having to adapt to the advancement of technology and innovation, needs to deal with the challenges that the world faces such as social justice, climate crisis and the pandemic (Ostrom et al., 2021).

2.5.1 Service design for sustainable services

According to Shirahada et al. (2011) a sustainable service is the one that meets the needs of current providers and recipients in terms of mutual value co-creation while without compromising the quality of future value co-creation.

Designers have a direct impact on the development of products and services that affect society and the environment. The application of sustainable design can considerably decrease the environmental and social impacts however, the use phase of these products and services on the entire the lifecycle is not evaluated in detail (Bhamra et al., 2011).

The development of services also requires the active participation of stakeholders and consumers to have a mutual value co-creation (Vargo and Lusch, 2016). However, it is not clear how this cocreation, that depends on sustainable behavior change, could work. Considering that the mutual sustainability effort is brought up as opportunities for future research by Ostrom et al. (2021), this presents questions about how sustainable services can engage the customer, such as transparency in service processes and their environmental effects, whether gamification can

help motivate customers to become more involved in reducing of waste, or how to implement a waste reduction routine without overloading customers.

Coskun et al. (2015) also reinforces the lack of relevant numbers of strategies while promoting sustainable behavior change to different target users but suggests, through the peer-reviewed research, conclusions that reward strategies; commitment and goals setting; and maintain engagement through feedback loops; could be successful ways to promote the change.

In a more practical terms, the method ECO-SD was conceptualized to help eco-design specialists to visualize and incorporate design requirements related to user experience while helping service designers to incorporate environmental requirements in new service concepts (Sierra-Pérez et al., 2021).

Manzini (2017) developed a framework concerning social innovation and sustainability presenting the design-orienting scenario approach, where it is articulated in three components:

- Vision: Brings an image of the whole context if life that would take place the new service developed.
- Proposal: needs to be feasible and aims to answer how the vision can be transformed to a real scenario.
- Motivation: explains the relevance of the scenario and is composed of generic and specific goals for its assessment.

Another approach that service design can adopt to design new sustainable service is through a robust data collection and analysis. Using customer behaviors data for service design can enhance the efficiency and effectiveness of the service design process (Maglio et al., 2016), facilitate design activities in service firms (Ostrom et al. 2015), and gather feedback to understand the customer experience. For instance, a case study was conducted to design a new eco-driving service concept based on bus driver's behavior data to decrease fuel consumption in the South-Korean transportation sector (Kim et al. 2018).

Another example that can be cited for the use of data for the improvement of services is the one from Xu et al. (2021) which proposes to offer personalized multimodal travel service based on SPSS (Smart Product Service System) for a better acceptance of people in relation to multimodal public transport. The idea is to provide route recommendations based on individual preferences that can be improved during it usage.

Although the service design is increasingly concerned with addressing sustainability issues, there is still little evidence and tools that prove the effectiveness of a particular approach, whether to promote behavior change or to use as a development, ideation, and evaluation of services.

2.5.2 Designing complex service ecosystems

Services are everywhere, and they are becoming the main leading drivers of the economy (Foglietti et al., 2017), being involved deeply in the current human activities (Field et al., 2021). Before the rise of the service economy, the old economic perspective was built on the so-called Goods-Dominant Logic. This paradigm changed with the new vision of the role of services in business and economic exchange (Vargo and Lusch, 2004). The service-dominant (S-D) logic represents a broader perspective of markets compared to the traditional perspective of markets that focus on the exchange of goods, referred to as Good-Dominant Logic (G-D). In S-D logic,

exchange processes that integrate knowledge and skills are focal when exchange is seen as value co-creation. (Chandler and Vargo, 2011)

In the service design field, there was an increased integration of service-dominant logic, and therefore the conceptualization of service design has evolved from "design of services" to "design for service" over the last decades. (Wetter-Edman et al., 2014).

As extending the context of S-D Logic has been developed into the ecosystem perspective, considering the emerging issues related to public services, solving social challenges, and dealing with multiple interactions on how people, machines and service providers can interact, there is a need to service design broad its scope to design services at the ecosystem level. (Sangiorgi et al., 2017)

A service ecosystem is defined as a “relatively self-contained, self-adjusting system of resource-integrating actors connected by shared institutional arrangements and mutual value creation through service exchange” (Lusch & Vargo, 2014) while service ecosystem design is a process of collective designing that involves actors in making, breaking, and maintaining institutional arrangements by showing how existing and interrelated rules, roles, norms, and beliefs strongly interact.(Vink et al., 2019)

Designing a service in an ecosystem view allows designers and firms to extend the context of the experience and include the multiplicity of social practices and processes (institutions), the value-in-cultural-context, considering the social norms, beliefs, symbols, and the co-construction of context, by reevaluating and redefining the future experiences based on the evaluation of experiences (Akaka et al., 2015). Although service design is considered a catalyst for innovation (Ostrom et al., 2015), some projects ignore the different layers mentioned, and in addition, the services implemented run the risk of not providing lasting changes since some services do not adapt to new realities that are in constant change.

Concerning this, Vink et al. (2021) propose a multilevel service ecosystem design process leading to the expansion of service design beyond projects by recognizing the plurality of design and non-design processes that influence the long-term outcomes of service design. In the conceptualization of service design, they propose four conceptual building blocks:

- **The Purpose of Service Ecosystem Design:** The service ecosystems perspective reinforces the focus on recognizing new value co-creation phenomena, meaning that the results of the service ecosystem design are not controllable and predictable, but rather adapt to instabilities and spontaneity. It is important that the recognition of value co-creation does not focus on a user or customer, but on different categories of actors that interact within this ecosystem, as these actors can perceive the results of the service ecosystem design in different ways.
- **The Materials of Service Ecosystem Design:** The design materials of the service ecosystem consist of the recognition of institutions (rules, roles, norms, beliefs), and in conjunction with the facilitators of value co-creation, which are called institutional arrangements. Institutional arrangements allow granting or constraining how value is co-created through resources integration, bringing its core materials to the service ecosystem. The service ecosystem's focus on these materials is not only to consider interfaces and physical contact points, but also invisible institutional arrangements through symbols, activities, and interactions. Because institutional arrangements are based on regulations, cultural and social norms, it is recognized that their reformulations are challenging, as they have a durable character due to their intense long-term propagation within the ecosystem.

- **The Processes of Service Ecosystem Design:** According to the service ecosystems perspective, actors are guided to reproduce routine behaviors implied by institutional arrangements. However, actors can intentionally shape service ecosystems by reconfiguring the institutional arrangements that guide them. Design processes are part of a continuous reproduction existing institutional arrangements and is focused on reformulating these arrangements. This reform can create, disrupt, and maintain institutional arrangements. After that, new processes of reflexivity take place when looking at institutional arrangements again, thus resulting in a feedback loop of design processes.
- **The Actors in Service Ecosystem Design:** This block considers the need to zoom out to understand the various constellations of actors influenced by ongoing interactions within and between conflicting processes and aligned and non-design design. From a service ecosystem perspective, the design of service ecosystems is carried out not just by professional designers or a selected group of actors, but by all actors within and affected by service ecosystems. Actors are continually shaping institutional arrangements that guide value co-creation, but they also have an actor-actor relationship that goes beyond company-client relationships. This means that value co-creation occurs collectively, affecting the broader system, as the intentions of the design processes of different actors are not always aligned and, therefore, collective design involves dynamic and multidirectional processes.

Since there is a need of service design to act more actively in the challenges of multi-actor dynamics and interdependencies in complex service systems (Sangiorgi et al., 2017), this research aims to use this conceptualization of service ecosystem design to recommend long-term value co-creation forms by considering the institutional arrangements and their physical enactments, their actors, and how they can be adaptable through the exercise of reflection and reformulation, to the constant remodeling of institutions and interactions of the processes of reproduction of future services.

2.5.3 Service design tools

According to Sangiorgi et al. (2017) designing complex service systems requires the adoption of different approaches and tools to develop more strategic practices. One of these approaches is the conceptualization of service design objects proposed by Kimbell et al. (2017)

Kimbell et al. (2017) defines service design objects made up of different elements and actors and order them in three different perspectives. The first one is *service encounter*, focusing on the experiences people and their interactions with touchpoints provided by others. The second one is *Value co-creating-system*, which focus on the exchanges of resources and processes achieved by actors. And the third perspective is *the social-material configuration*, related to the exploration and investigation of dynamic social practices, emphasizing the sociability and confusion of the worlds in which services are located. She exemplifies methods and tools for each object, where customer journey maps can represent the service encounter perspective, and stakeholder map, can translate both at the service encounter level and at the value co-creation system level.

With that in mind, it will be adopted customer journey tool to represent the citizens journeys in different transport modes interrelating with the pandemic phases: pre-pandemic, pandemic, and the envisioning of the post-pandemic scenarios. According to Patrício et al. (2011) “*The customer journey refers to a series of touchpoints, involving all activities and events related to*

the delivery of the service from the customer's perspective". This tool can be used to understand and address customer needs and pains (Gibbons, 2017), highlighting the customer-centric character (Følstad et al., 2018). Furthermore, it can be an enabler to involve important stakeholders, such as policy makers, in the process of service design. (Buchanan et al., 2017)

The stakeholders map will also be adopted to visualize the arrangements of multiple entities that interact to co-create value (Kieliszewski et al., 2012) and define the level of attention and effort each stakeholder should be involved. (Interaction Design Foundation, 2018)

As this project aims to look at the ecosystem level, it's important to use tools that goes beyond the service encounter level. For this (Sangiorgi et al., 2017) propose the use of the ecology tool, which aims to map current resources, how they are used and connected, and how these can generate improvements for the well-being of the entire ecological system.

3 Methodology

This chapter describes the methodology followed in this study. In the first section, it is described the qualitative method selected to guide this investigation. Then, it is explained the research approach, describing the steps followed to obtain the results, including sample design, data collection and data analysis. Qualitative approaches have been gaining importance in design research. The field has become more affluent, refined, and influential over the past decades (Laurel, 2003). A qualitative study opens the angle since previous research with the desired broad perspective was scarce.

3.1 Project Approach

This study aims to understand the impacts of the COVID-19 pandemic on urban mobility in Porto, as well as explore how this industry is positioned in the face of technological advances and sustainability initiatives to face the climate crisis. Therefore, the study starts with an exploration phase through qualitative methods, which according to Corbin and Strauss (2008), it can be evaluated in a systematic way if its canons and procedures are displayed in an explicit way. For this, the method used pretends to show how data was collected and analyzed by using themes and codes and complementing them with data from literature review to naming some concepts or showing conflicts and restatements of findings bringing the researcher's voice in the results analysis.

To achieve the quality and credibility of the study, it's needed to start with the data itself (Charmaz 2006). Following this logic, the first phase of this study was an inductive and data-driven approach using interviews (Braun and Clarke, 2006) later combined with data from the bibliographic reference to provide a general picture of the of pre-established and emerging themes from the interview data, resulting in visualization of dynamic and complex connections between the actors involved in mobility services in a pre, during and hybrid pandemic contexts. During the exploration and service visualization, some service design tools are embedded to help with the understanding of the problems, opportunities and needs by exploring the “how and “why” of the facts (Stickdorn et al., 2018). The problems will be identified as barriers in the mobility services visualization with the use of customer journeys, and based on the identified barriers, implementation recommendations will be made for the different stakeholders of the mobility services ecosystem.

The following topics describe different qualitative approaches that will allow this study to collect data to generate insights for the development and evaluation of the recommendations.

3.2 Data gathering

Qualitative interview is one of the most common and important data collection tools in qualitative research, being used in qualitative inquiry of all kinds (Myers and Newman, 2007). There are different types of qualitative interviews: structured interview, unstructured or semi structured interview and group interview. To start the data collection, the type of interview chosen was the semi-structured type, since it will allow us to obtain previous and real-time experiences by those people that are part of the phenomenon (Gioia et al., 2013), and also because it fits with the exploratory character of this phase that may help us, through open-ended questions and improvisation, enable the participants to develop the topic, causing the exploration of some details which can be important (Charmaz, 2006).

According to Morse (2000), adopting semi-structured interviews result in a small amount of data obtained per question. Therefore, larger sample size is necessary to bring the richness of the data. What reinforces the adoption of semi-structured interviews in this study is that the interviewees had different backgrounds and ideas, making it essential to have a higher number of interviewees to reach a level of saturation sufficient to reach a level of relevance. That said, to achieve this relevance in our case was the involvement of 25 participants.

In the first phase of the interviews, which lasted from 30 to 60 minutes, remotely and in person, participants had invited to talk about their impressions on the following topics: (1) how the pandemic has affected general behavior and urban mobility; (2) what the perspectives for the future are; (3) how different technologies can contribute to the creation of new business models, mobility products, and services; (4) what the barriers and how to encourage the use of public transport and micromobility modes; (5) how to achieve carbon neutrality collaboratively. This sample encompassed a diverse set of actors with theoretical and practical relevance, including 12 specialists in mobility and technology companies (MTC), 1 specialist in behavioral sciences (BS), 2 councilors (Councilman for Civil Protection and Mobility and Transport and Councilor, Department of Urbanism and Public Space and Department of Housing) (CC), 5 employees of public transport companies in the Porto (TC), and 5 professors and researchers in the field of transport and urban planning (PR). All interviews were literally transcribed and analyzed using NVivo software (Appendix C).

3.3 Data analysis

Qualitative research is built through a “bottom-up” process of categorization and topic selection, resulting in the organization of data until it is established in a set of comprehensive topics (Creswell & Poth, 2018).

Since this study is about how to analyze multidisciplinary topics such as mobility services, sustainability, and the consequences of the COVID-19 pandemic in different stages and contexts, it will be used Thematic Analysis, which is a method that aims to find, analyze, and group patterns or themes in the data collected (Braun and Clarke, 2006). According to Braun and Clarke (2006), there are six stages to develop a Thematic Analysis, which was accordingly adopted in this research:

1. Familiarization with data: The audio-video data was transcribed, then reviewed to provide a general perception and familiarization with the overall data.
2. Generation of initial codes: By reading the transcriptions, some pieces of data were highlighted and transformed into initial codes that were named in a very similar way of the data itself. For instance, the quote *"There are very cumbersome procedures that require us to undergo a permanent and bureaucratically very dense scrutiny of everything we do and, therefore, in fact, the speed at which things change in the private sphere is very different from the speed at which they change in the public sphere."* was encoded primarily as *There is a lot of bureaucracy for the interaction between private and public companies.*
3. Searching for themes: This stage consisted of looking at the codes and figuring out how they can be related and grouped together. These themes represent the collective meaning of the codes and categories that support them. For example, the collection of categories related to the main incentives that would lead people to use more public transportation and alternative modes resulted in a theme called *Experience requirements for public and alternative transport modes.*

4. Reviewing themes: New codes were created based on the comparison of the first and second phase of coding. This process ensured that the themes were matching with the pieces of data coded and with all the data set.
5. Defining and naming themes: Each theme was revised and refined to describe the data that were part of each group. Through this definition, relationships of affinities and contrasts between the themes were created, allowing a deeper understanding of the data.
6. Producing report: After identifying themes, a new demand for literature review was necessary to compose the analysis and build consistency in findings. (Nowell et al., 2017). It enabled the report creation presented in the Chapter 4 of this dissertation.

4 Results

4.1 Qualitative study results

To better understand what the impacts of the pandemic on the mobility sector were and what are the opportunities in technological and sustainable terms, this qualitative study focused on three elements: first, it was examined a set of perceptual responses on changes in mobility patterns and behavioral during the pandemic. Second, it made it possible to understand the main barriers and opportunities in the application of technologies in the mobility sector. Third, it facilitated the understanding of barriers and opportunities in implementing more sustainable mobility. This generated a set of 261 primary codes that were first grouped into 11 sub-themes and then aggregated into 3 global themes: Mobility and Urban Planning, Experience requirements for public and alternative transport modes, and Carbon Neutrality).

The categorization process used a bottom-up approach, as mentioned in the previous section. It means that relevant pieces of transcripts were selected and created as codes. From these codes, requirements patterns and trends were identified and then grouped into sub-themes. During the analysis of these sub-themes, it was detected essential points to achieve global goals (such as Mobility and Urban Planning; Define experience requirements for public and alternative transport modes; and achieve Carbon Neutrality), resulting in the categorization of the three global themes (example in Appendix D). Below, in the Figure 4 is presented a graph that displays the global and sub-themes ordered according to the relevance in terms of the number of mentions.

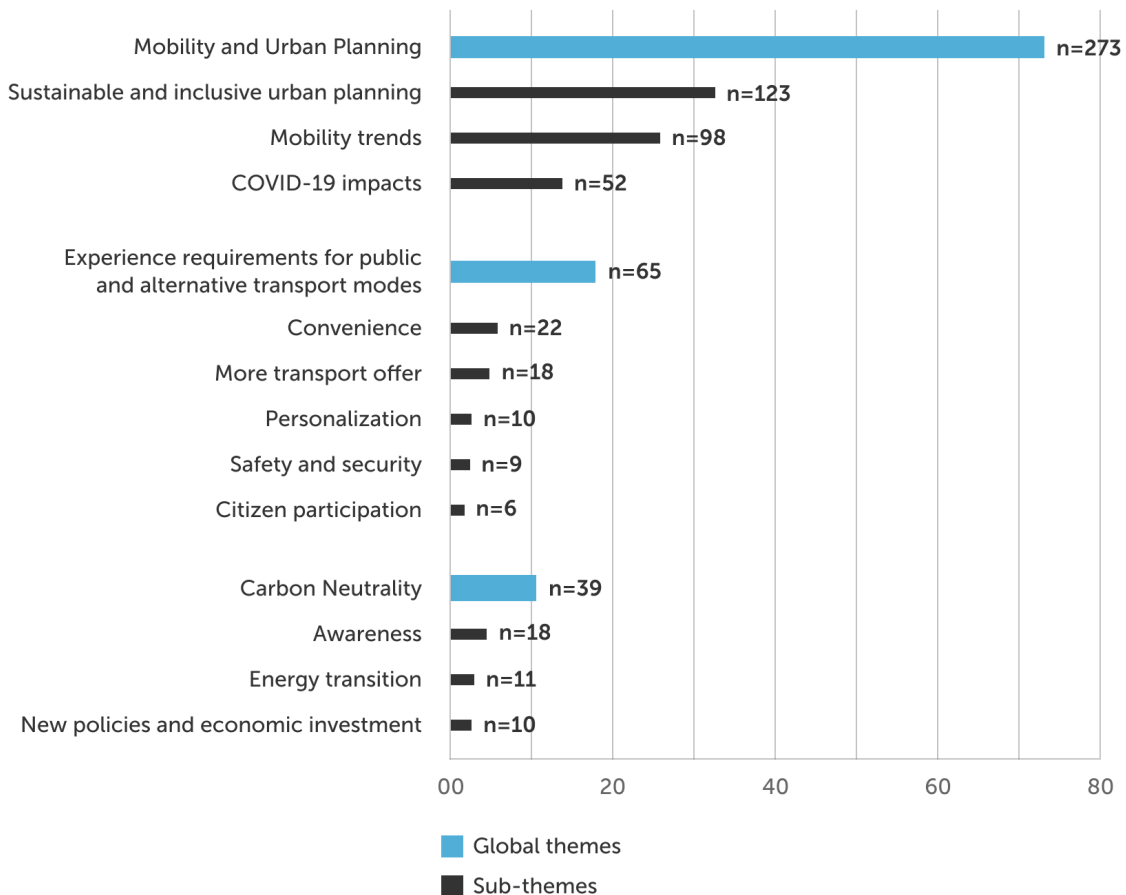


Figure 4 – Global themes and sub-themes.

Mobility and Urban Planning

Sustainable and inclusive urban planning

Management and government shared vision

There are political barriers related to the implementation of a good integration between transport modes and its distribution in the city. It is necessary to have good urban planning, and it requires time and effort from multiple actors and institutions to work. However, this planning execution exceeds the political cycles every four years, causing a non-continuation of the initiatives.

“The initiatives are thought every four years...then the political agreement is changed, the people change, and there is another view. And as there is not a defined strategy combined with all the stakeholders and plans involved, it causes mistakes.” (MTC_1)

Other interviewees (such as MTC_3 and MTC_12) mention that it is necessary to think about mobility beyond the county limits. When asked, one questioned about this issue, the interviewee from the CC group says that the trend is that the planning practice has evolved and is thought holistically, beyond the limits of the municipalities.

Initiated in March 2015 and approved in 2021, the Municipal Master Plan (PDM)¹ is the main Territorial Management Instrument of the Porto City Council and defines the way that territory is organized, establishing rules and guidelines of how the occupation should occur, as well as the use and transformation of land for the territory of the municipality of Porto must obey. In terms of Mobility, the proposed revision of the PDM focuses on stimulating three axes: public transport, parking and soft modes, investment in collective public transport involves defining the structuring network of BUS corridors, and betting on intermodal terminals and the provision of car parks to the major axes adjacent to public transport. It also proposes the progressive elimination of parking along streets and public spaces. (Baganha, 2021)

Another relevant factor that can contribute to mobility management is the law RFPPT (2015) that transferred the planning, development, and management of public transport systems from national to local authorities. This change represents an opportunity to introducing new planning tools and reinforce the competitiveness of public transport in relation to the private car, as there is the possibility of establishing a variable geometry configuration, allowing transport authorities to adapt to the mobility needs of the city population. (Silva et al., 2021)

What can negatively impact urban planning versus political cycles is that citizens are also pressing to see the results implemented by the government.

“Citizens don't want to wait, they want to have immediate results on the ground, the politicians start to do constructions and these constructions sometimes don't have planning results.” (MTC_10)

For this, it is also necessary to increase citizen participation in transportation services and urban planning. For example, interviewee MTC_5 says that public participation not only helps to understand users' needs and problems, but also creates public sessions to clarify the mobility planning initiatives.

¹ Municipal Master Plan (PDM), see <https://portoinnovationhub.pt/wp-content/uploads/2021/04/SbO22-PDM-1.pdf> (in Portuguese), accessed 05 June 2022.

Infrastructure

In order to have a better management of mobility and urban planning, it is necessary to invest in infrastructure, mainly integrated with technologies that can provide more efficiency and effectiveness for city managers and citizens.

For example, in traffic planning, installing sensors in the city, and GPS data collected by means of transport or people's cell phones can help to better plan the city:

“...define new traffic planning, where cars should go from one area to another, or whether cars should pass through the city center, but it would be possible to define other paths. I believe that with more detailed mobility surveys, and GPS sensors installed on people, it would be possible”. (PR_1)

Investment in express bike lanes can stimulate the use of alternative transport modes and can connect suburban areas to major stations or city centers.

“...these express-ways for alternative transport, I think it will be able to convince people who are not yet using the soft modes” (TC_3)

“Having a space for the cyclist to not be too vulnerable, if you're going to ride on the highway competing with a car at high speeds, there are people who don't even consider this hypothesis, right. But I see several countries investing in express bike lanes to connect cities.” (PR_4)

There is also a counterpoint that is related to the people's mentality, not only investing in infrastructure, but also changing the behavior of drivers of cars, bicycles, and scooters.

“I think public policy is to change some infrastructure but change people's mentality. I don't see it being done. I think it's a behavioral issue. I think that's the first barrier, which is behavioral and must be changing the behavior of car drivers and all people who want to use alternative transport.” (BC_1)

“This is not a competition. It is working for the general good. Yeah, I think a behavioral change is needed.” (MTC_8)

Other types of infrastructure were mentioned, such as the storage of bicycles and scooters.

“Then there is a big barrier in urban areas. Which is where to store the bike unless you have the garage, which is a minority of the population. And this problem must be solved. A lot of people still want to create on the bike, but they don't have the conditions to store the bike, because they won't take the bike up and down every day, but they don't have space in the elevator or they don't have space at home, and they won't leave it in the street, because sooner or later it will be vandalized or stolen.” (MTC_4)

To support this last point, a study was conducted in Lisbon to understand the motivations for using bike sharing during the COVID-19 pandemic. What can be highlighted from this study is that the motivations to stop using bike sharing were not associated with the pandemic itself but linked to the coverage and quality of the system. For example, the shortage of shared bikes, lack of stations near their destinations or home, and poor condition of the bikes were the main reasons for quitting the system. (Teixeira et al., 2021)

COVID-19 impacts

There was a decreased use of public transport due to remote working and fear of contamination. Despite this, operators continued to offer their services and applied policies to avoid contamination. The demand for public transport increased in periods of greater flexibility, however, has not yet returned to the expected numbers. As mentioned by an interviewee from the transport companies' group:

"...we should be doing around 290 and 300,000 validations and we continue to do 220, 230 thousand validations per day." (TC_2)

This statement is confirmed when we look at the INE (2020) report which states that there was a decrease in passengers by 44.7% in Metro do Porto, and 41.7% in Comboios de Portugal.

Some people started using bicycles, scooters or begun walking to avoid agglomerations, resulting in a temporary change in the way of transporting themselves during the lockdown, which did not take hold after the flexibility of the pandemic according to an interviewee from PR group:

"...here in Portugal, we do not act quickly to promote the alternative mobility as general mobility has returned and traffic levels have returned to the same levels as before the pandemic, although we still have a lot of people at home, or traveling less, the problems are even worse than they already were." (PR_3).

As there was not a permanent and relevant modal shift in Portugal to cycling, scooters, or walking and the fact that public transport was one of the most affected modes of transport in terms of use during the pandemic, people turned to cars because they felt safer and efficient, as there was no traffic during lockdown periods.

"...The issue of customers who, due to the pandemic, due to fear, ended up buying private vehicles and today use private vehicles." (TC_2)

The IEA (2020) confirms this fact, showing that in many cities, private cars were the most dominant form of transport during the Covid-19 crisis, as people sought to reduce their exposure to the virus in mass transit.

However, it is possible to draw positive conclusions from this new adoption of alternative means of transport.

"The other good thing that it brought was that it allowed us to understand that mobility by bicycle was important for the city. Therefore, many of these pop-up bike lanes began to appear. People traveled by bicycle because it would avoid having too many people concentrated on public transport..." (MTC_4)

The pandemic brought flexibility in working hours for those who had to go to offices, it created opportunities for coworking spaces for those who were unable or adapted to work from home. From companies' perspectives, physical offices were no longer needed. Due to the low level of mobility, the demand for public transport and the monthly pass dropped and became less necessary. According to the interviewee from MTC group:

"...remote work will be a great benefit for cities because we will effectively achieve

something that we almost never, if ever, managed to do, which was to reduce the demand for transport in general, right? The peaks reduction flattens the curve making demand more evenly distributed throughout the day. Then why? Because employers realized, companies realized that having the employee at home is not so bad, it even increases employee productivity." (MTC_7)

While MTC_12 interviewee agrees that there was a good adaptation to remote and hybrid work, which can bring physical and mental health to people, and help in the decarbonization of the city.

Adrián et al. (2021) states that that hybrid or remote working is likely to stay and can grow even further in digital sectors, and that this model can increase worker productivity and well-being, as well as help governments meet decarbonization targets by reducing related CO2 emissions. However, it's important to understand that there are niches when talking about the adaptability to remote work and lockdown effects, being necessary to consider other groups of people and family structures. For instance, in Portugal there was an increase in mental health issues during pandemic, especially in rural areas (OECD, 2021). There are also studies that reinforce the need to analyze the benefits and harms of families with children at home combined with remote work routine. (Möhring et al., 2020)

In terms of logistics, it was possible to observe the increase in the efficiency of transporting goods and how they work, as mentioned by an interviewee from MTC group. This type of transport had its demand growth due to the higher numbers of orders from e-commerce stores due to the lockdown.

"...one of the good things about the pandemic was that it allowed for the first time to understand how the transport of goods works within a city because it was the first time where there were really no problems. There were no problems in terms of traffic because the city was only available for the logistics part, and in terms of efficiency it became much more efficient, because the probability of people being at home was much greater. That's why we didn't have a delivery failure." (MTC_4)

People returned to live in smaller cities to have more space and quality of life since remote work made this reality possible. However, an interviewee from MTC group brought a concern claiming that public transport is not available in these areas and that the risk of congestion points is high.

"...this possibility of people going to live, moving further and further away from large urban centers to occupy smaller urban centers, where, in theory, they will be able to have a better quality of life, and at the same time, they will, most likely, start to generate congestion phenomena in these cities that today are no longer there" (MTC_6)

Mobility trends

Interoperability

According to the IEEE Standard Computer Dictionary interoperability is *"the ability of two or more systems or components to exchange information and to use the information that has been exchanged"* (Geraci et al., 1991). A more user-oriented characteristic is explicit in the definition of ISO/IEC 2382 Information Technology Vocabulary, that defines interoperability as *"The capability to communicate, execute programs, or transfer data among various functional units in a manner that requires the user to have little or no knowledge of the unique characteristics of those units"* (ISO, 1993)

This concept was mentioned by some interviewees and can enhance the other trends mentioned in the interviews, as they are services that demand intense data communication. For instance, the door-to-door planning, where interviewee PR_1 says:

“...I saw several project proposals, I have even seen, from the point of view of startups, award-winning, but one thing that still doesn't exist is the door-to-door planning. I come from my house to a friend's house who is in another city, and someone does this planning for me. That is, I don't have to do the planning...” (PR_1).

The interviewee MTC_8 speaks about a similar idea:

“If I had a capsule, that could pick me up at home and take me to the destination in a safe way, even if it took more time, and I could go to work with connectivity, all of that would be wonderful.” (MTC_8)

Mobility as a Service

Interviewees mentioned MaaS as a trend of the future for different reasons, which has the interoperability as a pre-requisite for the most mobility planning, booking, and playing. (Giesecke et al., 2016)

Other mentions MaaS from a convenience standpoint:

“Choosing mobility through an application that gives me the various alternatives of transport, a visible path, increasingly integrated, including payment.” (MTC_5), “and I want to deal with this only with the application and I don't want to be bothered with the different transport operators that will do this service for me...” (MTC_10).

And to stimulate resilience of the population:

“The ability to encourage good behavior in the municipalities. Municipalities need to make an investment and convince citizens to adopt these transport solutions as soon as possible so that these transport solutions have a positive impact on people's lives.” (CC_1)

The concept of Mobility as a Service (MaaS) comes from a study requested by the City of Helsinki that sought to reorganize the passenger transport sector to anticipate the problems that would occur due to urbanization, population increase and environmental issues. (Heikkilä, 2014). It can be defined as an umbrella to guide people to plan, book and pay for various types of shared or individual mobility through a digital channel such as smartphone applications. (Karlsson et al., 2016)

Some pilot projects were tested in Porto by public entities, as mentioned by interviewee CC_1, but still without much success in their applicability, according to PR_3. This is due to the difficulty of tariff integration between the different tariff operators, as mentioned by the interviewee from the TC group:

“The difficulty is always tariff integration. Combine the various pricing systems, and information, making it the only one. Technologically, I think we already have some maturity to move forward. The difficulty is bringing together several service providers.” (TC_1)

This links to other types of barriers: Political and Legal barriers. There are private companies that want to bring technological solutions to implement integrated or MaaS services, but they

find some difficulties to contact public entities for a possible negotiation, due to the requirements of public tenders that start-ups cannot delivery. In addition, there is a bureaucracy and fear among these partnerships. Interviewee MTC_3 talks about the difficulty in making partnerships and developing projects in systems that would probably not be able to integrate their product because the hardware and technological architecture used in public transport systems is very obsolete. To tackle these barriers, a legal and political push would be needed to make this integration, not only technological, but also among companies:

“...in technological terms, I believe that there is everything needed to radically change the way we consume mobility. With some sadness, I think it is in almost all markets, today it is the regulators who determine the existence of markets...” (MTC_3)

Most part of interviewees report that the combination of technologies can be used to stimulate citizens and entities that govern cities to create a cleaner, optimized, and safer city and mobility:

“The triangle here is 3 technologies that I think can be completely game changers. One has to do with blockchain I just gave some examples. Another is IoT because sensing is essential for you to be able to control mobility in environments that are open environments. And 5G, other technologies like that that allow you to connect the IoT and the sensors, with the central systems, are critical. And then, the third Pillar of the triangle, which is artificial intelligence, everything underneath all this has the data lakes. Artificial intelligence, combined with sensors and combined with these chain services, which bring confidence and traceability to a service are magical and I would say they are the top 3.” (MTC_8)

Linked to these technologies, it would be possible to offer predictive and customized features to the citizens and entities involved, as mentioned by the interviewees TC_3, PR_2, and PR_5.

In addition, these technologies can contribute to the acceleration of carbon neutrality as the use of shared or electric transport, as well as sustainable behaviors could be reversed in credits/points and consequently increase citizens' motivation to make more environmentally friendly choices. If these rewards, together with the new technologies applied, in an efficient and immersed way into people's daily routine, it could sustain a durable behavior change. (Coskun et al., 2015)

However, there is a big issue regarding data collection. Currently, the transport systems in Portugal and even more in Porto have failure to collect and use data. This problem became evident in mobility studies during the pandemic, as mentioned by an interviewee from PR group:

“For a few months, basically the system was open, both the bus and the subway. People didn't pay. This, even in terms of our studies on mobility, has brought us prejudice. During that initial break of the pandemic, while things didn't start to prepare for the first opening which was in mid-April, we don't have substantial data on that.” (PR_5)

Concerning this problem, interviewee CC_2 states that one of the priorities of the municipal plan to overcome these barriers in data collection will be monitoring the city through the integrated management center where it will be possible to collect data on traffic, public safety, cleaning, etc. There are also initiatives based on partnerships with GPS companies to share information in real time and increase mobility efficiency. Furthermore, the interviewee TC_3 revealed that the company AMP together with the Metropolitan Councils of City Councilors

for Urbanism and Mobility and the public transport operators are working to ensure that there is real-time control of the operation for a more effective planning of the mobility. Considering these initiatives, citizens will need to be open and knowledgeable about mobile data sharing and know what benefits it can bring them.

“We must provide some information so that the systems can work, ok? All of us today and this is an example which is the most talked about and which is the best known. Everyone uses Google, everyone uses Google. And use it for free. Why? Because they are giving access to your data, location.” (MTC_1)

Regarding the individual transport of people and goods, respondents MTC_4, MTC_9, and PR_2 reported a trend of substitution of gasoline-powered vehicles for electric and autonomous vehicles and an idea that people will have fewer private vehicles, with a transition and emphasis on shared mobility and public and alternative transport. To sustain this trend, some cities like Barcelona, London, and Stockholm are rethinking the role of private cars and increasing the restrictions and charging fees for them to access certain areas of the cities. (Dixon et al., 2020)

Experience requirements for public transportation

Convenience

Still on the technological barriers, there is a belief that the necessary technologies already exist to offer mobility services that fulfill the user's needs. However, there is much to be done in terms of experience and convenience, as it is not treated holistically according to two interviewees from the PR and MTC group, respectively:

...they're all different platforms. I buy tickets on totally different sites. Do the math to find out how much it costs. And to compare, to know how much it costs or the carbon footprint or whatever, it is this fragmentation that comes from the fragmentation of operators. Basically, this is a consequence of the deadline, the action of the operators and the responsible entities and I have seen since 2010 that I see projects to solve this technologically from time to time. Therefore, I believe that technology is not an issue. (PR_1)

“I'll give you an example here, in the Lisbon area, if I have to go from Lisbon, to the Cascais area, which is where I live by bike, I have to install at least 3 applications, put credit in 3 applications, this for me is stupid, for a tourist even more stupid it is, because he will not return to Portugal anytime soon and that credit will be lost, because many times we have minimum balances.” (MTC_8)

Safety and security

Security barriers are one of the points to be tackled when we talk about modes of transport by bicycle, scooters, and walking. Interviewee MTC_5 states that:

“The main barrier is still that people do not feel safe. There are many, but security is perhaps number 1”. (MTC_5)

The MTC_12 interview says that it is necessary to address the conflict points of intersections for pedestrians, and the PR interviewee adds

“Awareness, above all, of drivers or those who share the space and who do not use alternative transport modes, whether buses or drivers of normal vehicles of passengers, in which it is often noted that there is no sensitivity to perceive what is, for example, spacing between a vehicle and a bicycle, between a vehicle and a scooter...” (PR_5)

More transport offer

One of the first needs that were pointed out is the lack of public transport in Portugal, either due to the limitation of schedules and lines, even in areas where transport offer is not covered, such as in industrial and suburban areas.

According to two interviewees, MTC_5 and PR_5, new transport lines in low-density areas are not profitable and feasible, therefore it is necessary to find new, more tailored solutions to connect them to a train or metro station. Interviewee PR_2 makes some suggestions:

"There is this issue there has been a lot of conversation about integrating bicycle and scooter modes connecting residential areas to large stations. There has also been a lot of discussion about on-demand services for suburban and rural areas, where demand is not so significant and does not become so viable. But having a way to get people to public transport through these systems such as on-demand transportation that could be smaller buses or even cars." (PR_2)

As for the metropolitan area, there is a network expansion initiative according to a member of the TC group:

"The focus of our strategy is the expansion of the network, the expansion of capacity to reach more spaces within the metropolitan area of Porto, making the metropolitan area of Porto more cohesive." (TC_2)

Another fundamental requirement is the accuracy and frequency that public transport needs to have, especially buses. For this, it is necessary to invest in the infrastructure of the urban territory by building bus lanes so that this transport is not affected by car traffic. In addition, real-time information and timetables are not reliable for citizens, making this means of transport less attractive.

As a requirement for public transport operators, the inclusion and easiness of services should be considered, as currently most are not adapted for people with disabilities. The journey from buying the ticket to commuting should be mapped and improved, considering the optimization of the experience. One of the main solutions according to our interviewees, include tariff integration and registration for the use of micromobility transport.

For greater use of public transport and alternative transport, it is not enough to provide more transport, but to review the priorities that cities provide for cars. Some interviewees claim that the transport offer is important, but it is necessary to change the city's strategy, which was previously designed for vehicles, and now must prioritize bicycles, scooters, and pedestrians.

"...not necessarily creating bike paths, but creating urban environments where speed is lower, and making the lives of bike and scooter users easier and safer..."(MTC_6)

"...the car has very easy access, I think the car has to exist, obviously, but it should not be treated as the first alternative, it is one of the alternatives. More than making it easier, it is necessary to make access to cars difficult so that people can migrate more easily to other types of transport." (PR_4)

Carbon Neutrality

Some respondents believe that carbon neutrality can be achieved, especially if it depends on the younger generations. However, there is a certain pessimism because more sustainable attitudes depend on political and industry actions, and these entities do not have carbon neutrality as one of their main objectives.

“With this industrial matrix that we have, I'm not seeing people give up their comfort in a very expressive way when we have more and more incentives for more and more industries to produce products that are basically placed in plastics.” (BC_1)

According to CC_1, it is possible to accelerate carbon neutrality, but a big investment needs to be done.

“I believe that it is possible to accelerate the carbon neutrality to improve the quality of life of communities...now it needs a big investment in terms of public investment in good roads in an intelligent road network...Public investment in infrastructure is needed, it is energy efficiency, but also sensing and intelligence in public space that allows us to create a communication network in the municipal territory that helps all public services to connect more smartly and effectively.” (CC_1)

Furthermore, creating a sense of resilience and clearly showing economic gains and other incentives could instruct citizens to be increasingly aware of the issue:

“I think that in urban mobility, we can save a lot in both money and emissions. And gain in health.” (PR_1)

According to IEA (2021) report, the Portuguese government is working on many fronts to encourage a shift from private vehicles to public transport and active and shared mobility. There is the National Investment Plan 2030 that set investment priorities in the transport, environment, and energy sectors. Investments are focused on supporting the decarbonization of rail and public transport. In addition, the government has developed a National strategy for Active Mobility, which aims to increase bike lanes to 10 000km in 2030 and is subsidizing EUR 250 for the purchase of electric bicycles.

Final thoughts

Portugal is advancing with its policies to address the needs of transport integration and systems that guarantee interoperability. There is a perception that the problems to develop these integrations are already known by decision makers and stakeholders of transport services and urban planning. It can then be reiterated that the first step is to solve the issues by collecting and analyzing data from all modes of transport to detect problems and provide better and more integrated services so that alternative transports are more attractive and known for their efficiency and good experience.

Speaking about the carbon neutrality topic, Portugal was one of the first countries in the world to set 2050 carbon neutrality goals and it is in the leadership in the transition to clean energy, especially integrating electricity from renewable sources. (IEA, 2021)

Regarding the consequences of the pandemic, in addition to the social and economic impacts mentioned, there was a major process of processes digitalization with an increase in online purchases and ticket validation through digital tickets. Changing habits, such as remote working, affects and will continue to affect the demand of the mobility sector. There is a demand here to reinforce hygiene, social distance, and marketing in public transport so that people feel safe. It also brings opportunities to encourage the use of transport such as bicycles and scooters.

Offer more and better public and alternative transport services not only in central areas, but also in suburban and industrial areas, while at the same time overcoming cultural beliefs regarding the ownership and use of private vehicles can be the next steps. Designing policies to restrict

private vehicles in some urban areas so that congestion is tackled, as well as emissions levels are reduced, could also be consider making the transport systems more sustainable.

4.2 Stakeholders map

Before moving forward with the comprehension of the main opportunities and how it interacts with touchpoints and activities, it's important to identify the main stakeholders that could be involved for the development and validation of new products and services, new policies creation and adaptation, consultancy and feedback, and benchmarking.

As presented in the figure 5, the stakeholders are divided into four aspects: Companies, Citizens, Local Organizations, and Municipality & Governance. They were positioned based on the level of integration in new products and services developments.

The following stakeholders were selected and prioritized with CEiiA to ensure that the relationships have a realistic vision in terms of potential partnerships and value added instead of conflicts.

Table 1 – Stakeholder analysis

Level of interaction	Stakeholders	Strategies for involment
Core	CEiiA	Product/service development
	Target users	Interviews, validation processes
	Frente Atlântica	Political and Legal support of the municipalities of Matosinhos, Porto and Vila Nova de Gaia.
	AMP (Área Metropolitana do Porto)	Communication with different municipalities and transportation operations
Involved	Urban planning companies	Integrate the new mobility services with urban planning studies and initiatives
	CGI (Centro de Gestão Integrada)	Provide Porto's mobility data
	University/Research Institutions	Perform research and provide data and insights about the mobility sector
	TIP (Transportes Intermodais do Porto A.C.E.)	Provide consultancy around the tariffs and ticketing
	Renewable energy companies	Provide resources to develop products based on the renewable energy
	Electric mobility companies	Provide resources to electric products
	Telecommunication companies	Provide connection networks for mobility services
	Data Privacy Consultors	Provide legal consultancy about the data privacy and protection
	Urban Mobility Associations	Provide consultancy about effective accessibility in soft transport modes
	Municipalities in the Porto metropolitan area	Integrate the different strategies of Porto's municipalities
Monitor	Micromobility companies	Benchmark / Partnership negotiation
	Public transport companies	
	On-demand transportation companies	
	MaaS companies	

	Technological companies of smart and sustainable solutions	
	GPS technological companies	
	Electronic payment services companies	
	Local communities	Evaluate how local communities engage with the developed service
	Government	Monitoring priorities, initiatives, laws, and decrees
	European Union	

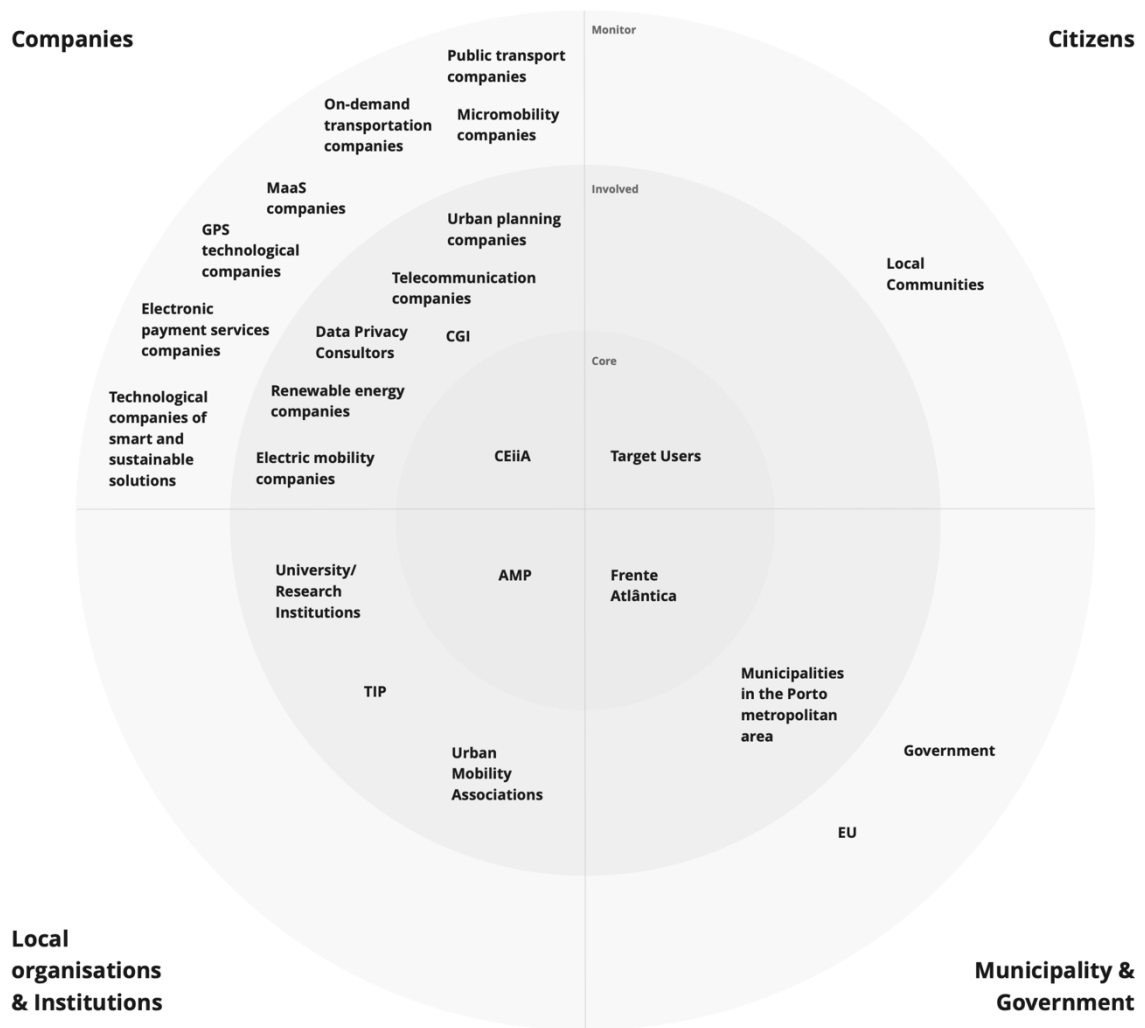


Figure 5 – Stakeholders map.

4.3 Mapping mobility patterns and barriers pre and during COVID-19 pandemic

After analyzing the interviews combined with the second phase of the literature review, it was possible to visually build an understanding of what was the citizens' journey in different types of transport in the pre and during the pandemic phases.

Based on the inputs of future trends, whether coming from qualitative data or the literature, it was possible to envision some improvements for a hybrid context and with this provide some recommendations.

The journeys' structure follows the aspects of actions performed by a citizen, its touchpoints, and the barriers that come from each step. This model emerged due to the specific needs of this project, but its structure is based on the ECO-SD method (Sierra-Pérez et al. 2021), which aims to visually identify barriers to environmental performance and user experience during service provision. Once the main steps and actions were mapped for each type of transport, service barriers were added based on inputs from the interview results. These barriers were categorized considering mainly what prevents the different types of transport from being safer in terms of infrastructure or sanitation due to the pandemic, and bringing the aspect of sustainability, questioning what are the environmental impacts that go against the goals of achieving carbon neutrality. In addition to these, other barriers were also reported in the qualitative study and placed in customer journeys, such as service, financial, and behavioral barriers, as shown in the Table 2.

For the hybrid pandemic context, a new table for each transport type were added to place the proposed solutions that might overcome the barriers emerged from actions and touchpoints, as well as bringing suggestions for a potentially improvement of the experience.

The journeys' phases were built from planning to the arrival of a commuting, and it was based on the following types of transport modes: buses, railway transport (metro and train), and bike and scooter sharing.

Table 2 – Barrier classification

Service barriers		Experience barriers Does the user lack information that facilitates the use of the service? Is there an increased effort to complete an action? Are there aspects of the service that make the user not use it or give up using it?
		Resources Are any mobility services not offered? Are the resources of mobility companies limited to offer the service at some point in the journey?
		Policies Are there established policies that shape service delivery and its norms/rules?
Technological barriers		Data barrier Is there a lack of data to convey information to the user? Is there a lack of real-time data monitoring? Is the data not transmitted accurately?
		Issue barriers Is there a problem in the system that is causing the impossibility of using the service?
Physical barriers		Architectural barriers Does the structure of the city not help the movement of people? Does city furniture impede free movement? Are there too many slopes or lack of sidewalks and walkways for people to walk safely?

	MT	Meteorological Are there weather conditions that could make the user not choose a particular service or opting for a specific transport?
	INF	Infrastructure Can the lack of urban infrastructure or the transport service prevent the user from using the service? Is there a lack of investment in infrastructure in any public space or transport on the journey?
Environmental barriers	EI	Environmental impact Does this behavior/use of a specific transport mode cause negative impacts on the search for carbon neutrality?
	ES	Environmental sensibility Is there a lack of knowledge or sensitivity in choosing a mode of transport that causes negative environmental impacts?
Sanitary measures barriers	SM	Sanitary measures Did health measures due to COVID-19 cause users to stop using a certain mobility service? Do health measures impact the way the user uses a particular service?
Behavioral barriers	CUL	Cultural Is there any cultural resistance to using a service? Is there a demand for behavioral and cultural change that causes a risk in the non-adoption of a service?
Financial barriers	FI	Financial Are there financial aspects that may prevent the user from not using a mode of transport?

4.3.1 Mapping the public transport commuting experience before and during the pandemic

Based on the results of the interviews, the service design method chosen to map the use of different types of transport was the customer journey, as it leverages a mode of temporal reflexivity, which allows an awareness of social structures through the experience of duration between events (Vink et al., 2019).

As mentioned before, the citizens' journeys on buses, rail transport and micromobility were mapped. For buses and rail transport, the journeys are similar as well as the barriers encountered before and during the pandemic.

The barriers that stand out most in the journey of buses are the lack of availability of transport in suburban or industrial areas, as well as the lack of punctuality, resulting in the lack of confidence that this type of service generates because it is not monitored in real time, making it difficult for the user to know if the information presented in applications that track vehicles is reliable. This fact brings a real demand for an improvement in the treatment of the collected data and its analysis. In addition, this service needs to make detour routes to be able to respond to the demand of a certain region, which, despite being something positive, impacts the experience of the citizen, who needs to stay longer in the vehicle, as well as the environment when the fleet does not consist in electric vehicles (Figure 6).

During the pandemic, as already explained in the literature review and in the results of the interviews, the use of public transport in general decreased, either through remote work, or through the adoption of alternative transport or private vehicles for fear of contamination. However, for those who continued to use them, the most relevant barriers are the social distance, with concerns related to maximum capacity in vehicles and air circulation conditions. There is also a mistrust about disinfection of buses, and finally, there was a lack of

standardization in ticket validation in some transport operators. Some turned off the ticket validation machines to avoid contact. Others encouraged the use of contactless payment via app or Andante card (Figure 7).

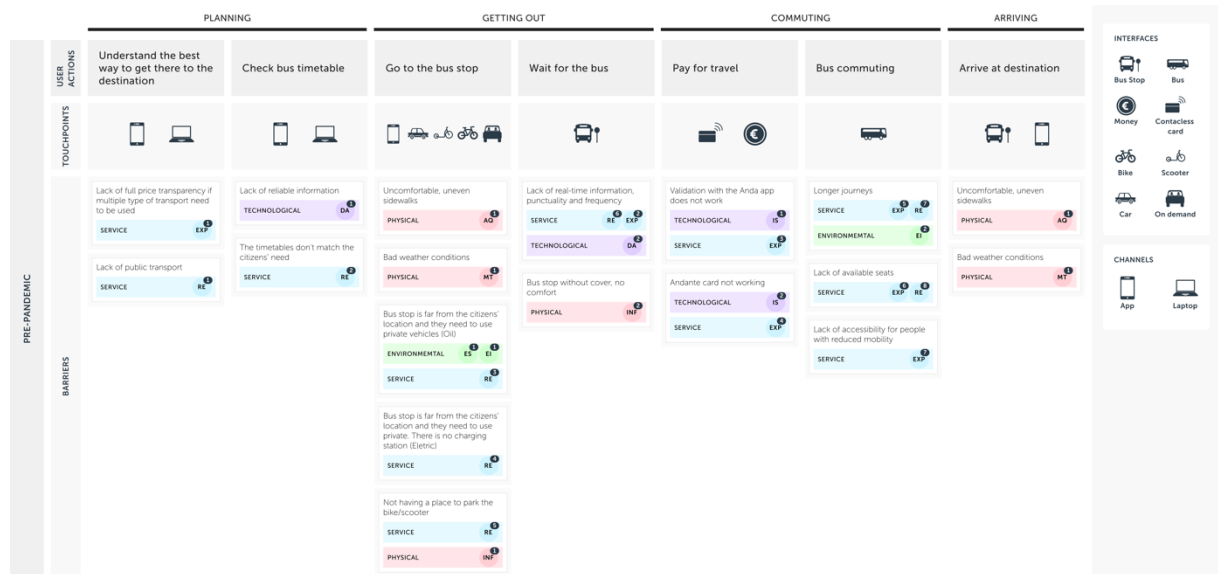


Figure 6 – Citizen's journey in using buses before pandemic.

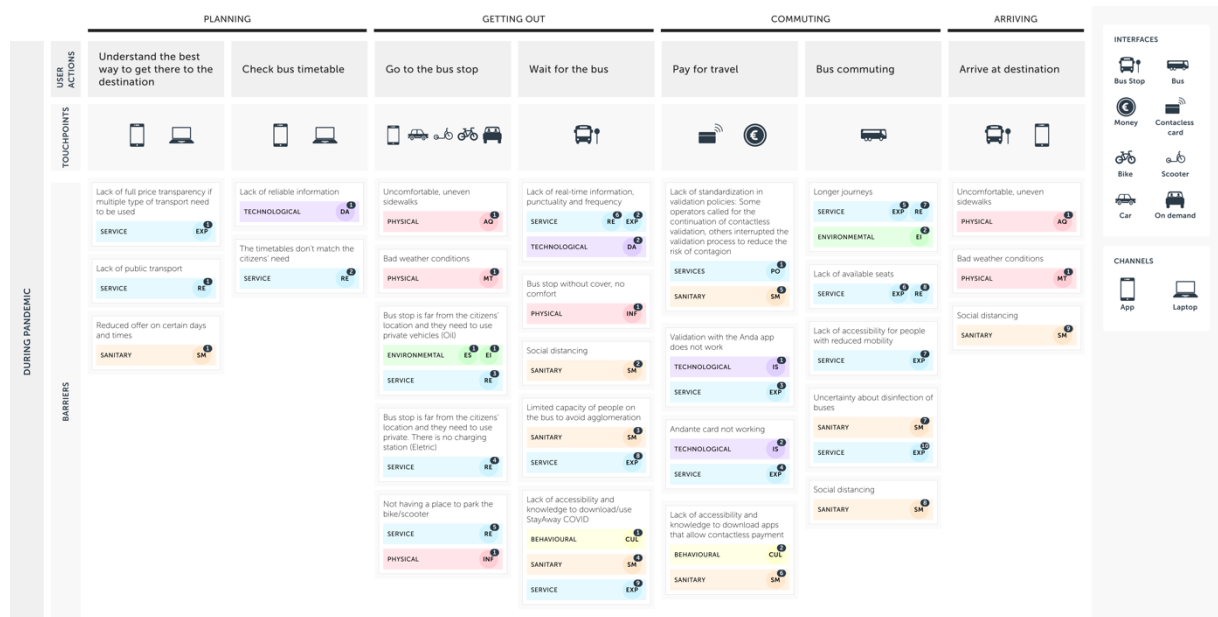


Figure 7 – Citizen's journey in using buses during pandemic.

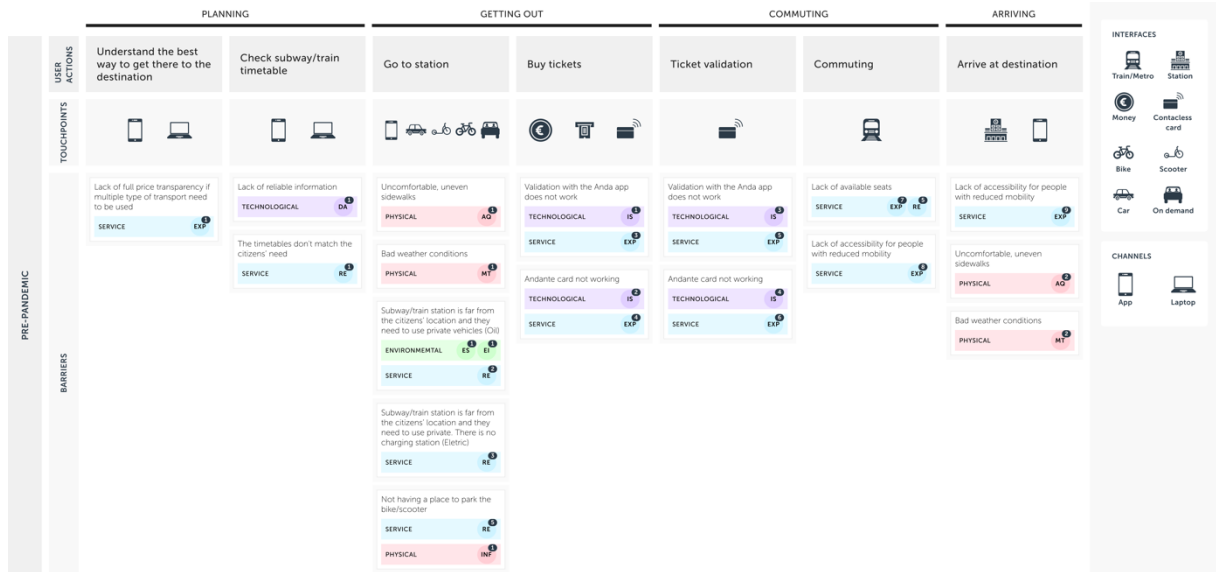


Figure 8 – Citizen's journey in the use of railway transport before pandemic.

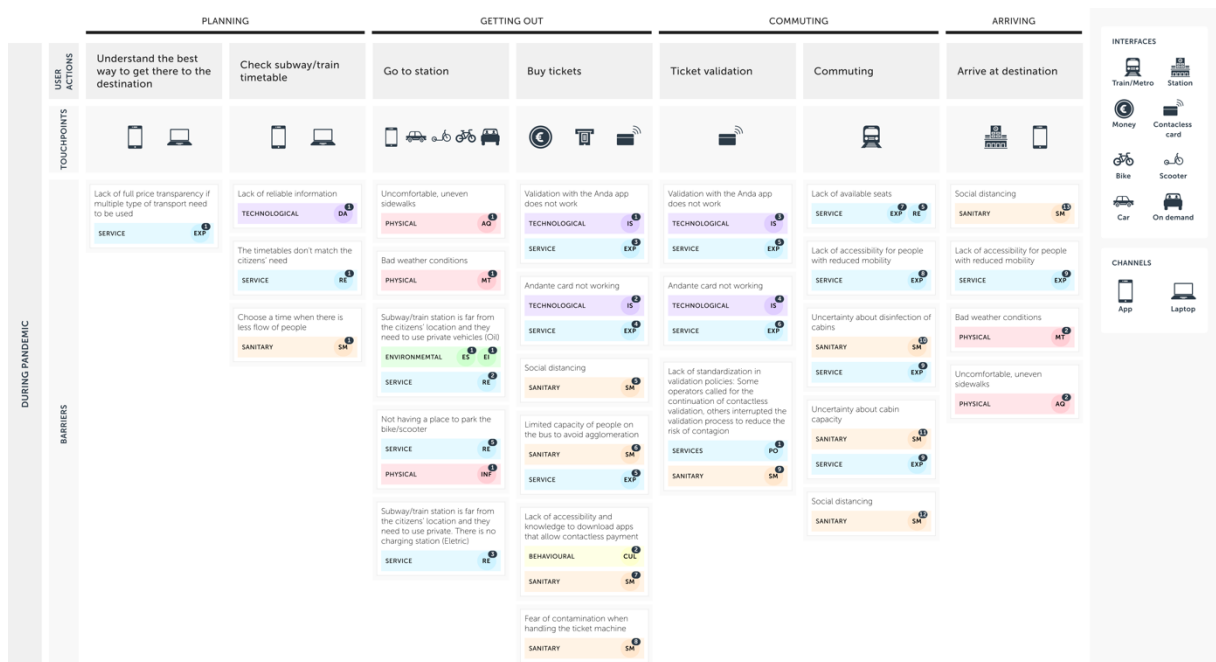


Figure 9 – Citizen's journey in the use of railway transport during pandemic.

4.3.2 Mapping the micromobility sharing commuting experience before and during the pandemic

Unlike public transport, people started using micromobility transport more during the pandemic to avoid agglomerations. Regarding the barriers encountered, barriers related to sanitary measures are not so relevant, thus making the pre-pandemic journey and during the pandemic not so different in terms of barriers as shown in the Figures 10 and 11.

The ones that stand out the most are the service barriers that involve the experience in applications, also the greater availability of sharing points in non-central areas of the city. As already seen in this research, micromobility transport could enhance people's connection to public transport, especially those who need to walk more kilometers to arrive in a station or bus stop. In addition, there are physical barriers, whether architectural or infrastructure, and

inadequacy of micromobility equipment for city environments. These facts directly affect citizens' confidence when adopting this type of transportation. Their safety when they need to cohabit with pedestrians or cars. Behavioral ones are also relevant as they affect the perception of other citizens about the group that uses this means of transport and may encourage or influences negatively. For this, an educational program focused on bringing out the best practices and reviewing policies on what is allowed and what is not needs to be reinforced.

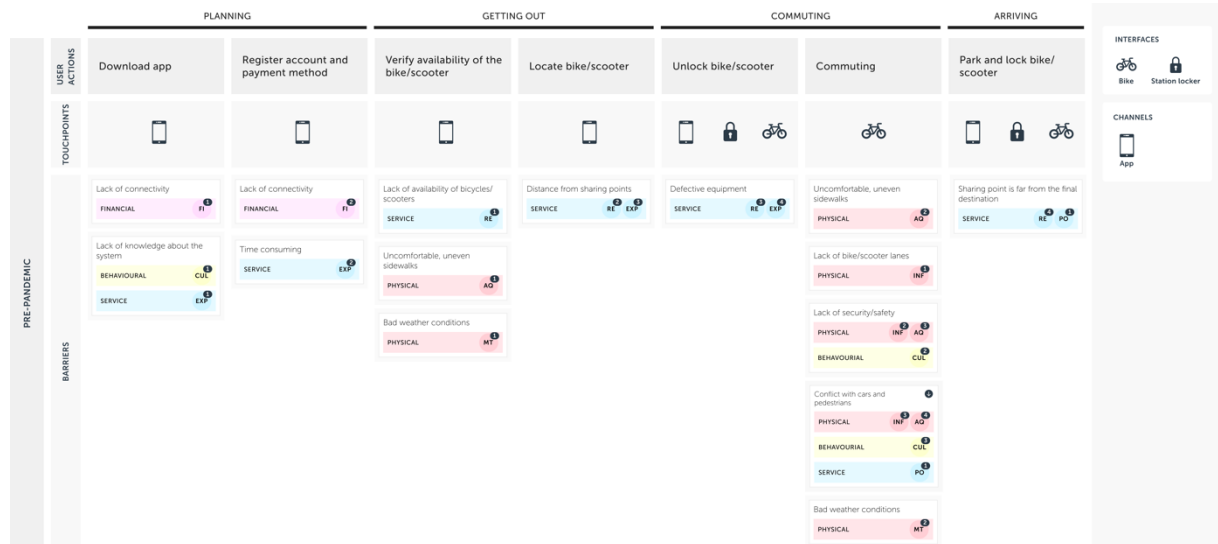


Figure 10 – Citizen's journey in the use of micromobility transport before pandemic.

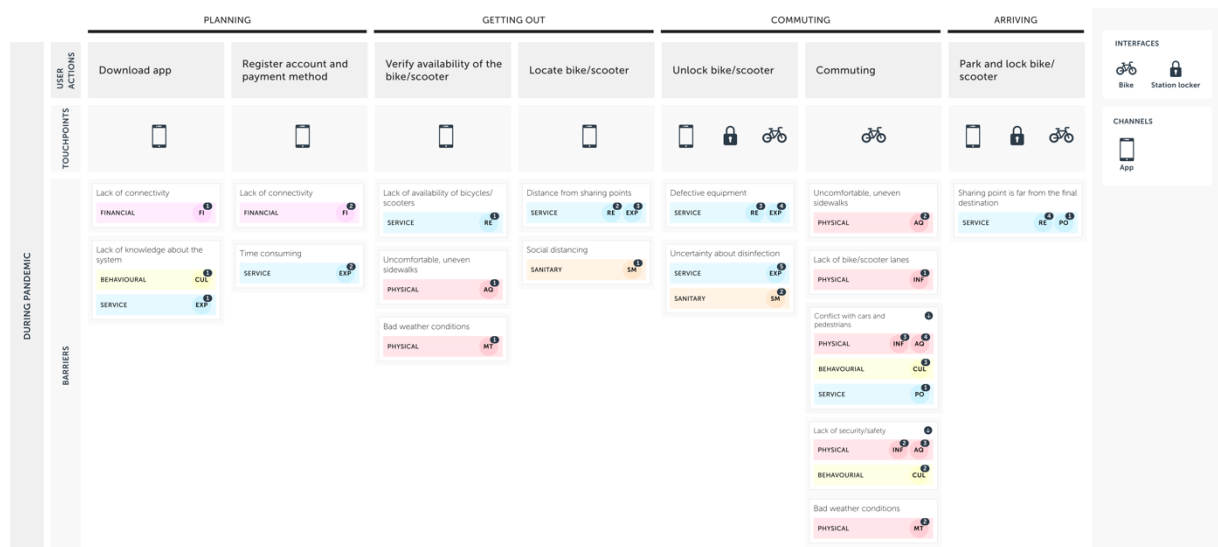


Figure 11 – Citizen's journey in the use of micromobility during transport.

5 Proposing solutions to address the identified barriers

Table 3 – Proposing solutions to address the identified barriers - Bus

Bus			
Barriers	Proposed solution	Benefits	Stakeholders
EXP1	Allow the user to plan the route with information on the total price for one or multiple commutes.	Bring predictability and influence the decision-making process for choosing a means of transport	- AMP - Technological companies of smart and sustainable solutions - TIP
DA1, DA2, RE6, EXP2	Improve data infrastructure of the bus operators	- Increase bus lines efficiency. - Increase the trustworthiness by providing real time data for the citizen.	- Municipalities in the Porto and metropolitan Area - CGI - AMP - Public transport companies
AQ1, MT1	Bring predictive information on route and weather conditions	Help the user choose the best means of transport	- Municipalities in the Porto and metropolitan Area - CGI - Technological companies of smart and sustainable solutions
RE 1, RE2, RE 3, ES 1, EI1, RE 4, SM1	Offer more first and last mile options such as car sharing, bike sharing, in suburban or remote areas to give access to stations or terminals.	Reduces dependence on private cars for travel and consequently improve environment and health outcomes	- Municipalities in the Porto and metropolitan Area - MaaS companies - Micromobility companies - On-demand transportation companies
R5, INF1	Increase the presence of docks and hangars to store bicycles safely.	Stimulate the use of micromobility transport as a first and last mile	- Municipalities in the Porto and metropolitan Area - Micro-mobility companies
IS1, IS 2, EXP 3, EXP4, PO1, SM5	Expand the installation of machines that accept credit cards for travel validation Stimulate the use of contactless payment	- Standardization of means of payment on buses and rail transport - Decrease the risk of contagion	- AMP - Public transport companies - Electronic payment services companies - TIP
INF 2, EXP 7	Improve accessibility, comfort, lighting, and safety in a standardized way of bus stops	Provide a safe environment for all people, including people with reduced mobility and other needs	- Urban planning companies - Municipalities in the Porto and metropolitan Area
EXP6, RE8, SM3, EXP 8, SM8	To include a functionality in the applications of monitoring of buses the	Visibility of the number of available seats that may imply	- AMP - Public transport companies

	occupation rate of the vehicles. Make available at the bus stops the occupation rate of the next vehicles	social distancing measures	▪ Electronic payment services companies ▪ Technological companies of smart and sustainable solutions ▪
EXP5, RE7, EI2	Increase availability of bus lanes	▪ Prevent the circulation of buses from being interrupted by the traffic of cars, and thus reduce travel time	▪ Urban planning companies ▪ Municipalities in the Porto and metropolitan Area
SM7, EXP10, SM2, SM8, CUL2, SM 6	Add information on how to use buses without taking risk of contamination in applications, bus stops, and inside vehicles Explain the disinfection process	▪ Increase people's confidence about disinfection and health safety in buses. ▪ Increase awareness on the best practices to decrease risk contamination	▪ Municipalities in the Porto and metropolitan Area ▪ AMP ▪ Public transport companies

Table 4 – Proposing solutions to address the identified barriers – Railway transport

Railway transport			
Barriers	Proposed solution	Benefits	Stakeholders
SM1, SM11, EXP9	To include a functionality in the applications the occupation rate of metro stations and its respective lines.	▪ Visibility of the number of available seats that may imply social distancing measures	▪ AMP ▪ Public transport companies ▪ Electronic payment services companies ▪ Technological companies of smart and sustainable solutions

Table 5 – Proposing solutions to address the identified barriers – Micromobility transport

Micromobility transport			
Barriers	Proposed solution	Benefits	Stakeholders
F1, F2	Increase free wi-fi public network	▪ Boost registration in micromobility apps for those with limited connection packages	▪ Municipalities in the Porto and metropolitan Area ▪ Telecommunication companies
CUL1, EXP1	Partnerships between public transport and micromobility companies to have discount coupons on bicycle and scooter rentals	▪ Stimulate the use of soft mobility and seek a cultural reaffirmation and demand for these types of transport	▪ Public transport companies ▪ Micromobility companies
EXP2	Allow quick registration with only necessary information.	▪ Seamless experience	▪ Micromobility companies

RE1, RE2, EXP 3, RE4	Increase the micromobility transport network, especially in suburban and residential areas Allow the user to book bicycles or scooters before reaching the sharing points	▪ Strengthening and availability can bring greater adoption of these transports ▪ The act of booking these transports brings greater confidence in the service	▪ Micromobility companies ▪ Municipalities in the Porto and
AQ1, MT1, MT2	Bring predictive information on route and weather conditions	▪ Help the user choose the best means of transport	▪ Municipalities in the Porto and metropolitan Area ▪ CGI ▪ Technological companies of smart and sustainable solutions
RE3, EXP4	Have a predictive system indicating the status of the equipment before booking. If reserved, allow the user to reserve other equipment, or show the nearest available equipment. If booked, provide discount coupons or credits for future use.	▪ Maintain trust in the service	▪ Micromobility companies
EXP5, SM2	When pre-booking the equipment, provide information if the equipment is disinfected. Offer materials for disinfection of equipment such as gloves or alcohol jets to pass on the handlebars.	▪ Provide sanitary security in the use of equipment.	▪ Micromobility companies
AQ2, INF3, AQ4, CUL3	Provide route options based on architectural barriers in the application: slopes, bike lanes, type of asphalt in a customized way	▪ Better confidence and safety for people who have less experience using bicycles and scooters in the city.	▪ Micromobility companies ▪ CGI ▪ GPS technological companies
INF1	Build bike lanes in suburban areas that connect residential areas to stations or main bus stops, and in city center points	▪ Encouraging the population to adhere to alternative means of transport	▪ Municipalities in the Porto and metropolitan Area ▪ Urban Planning companies
INF2, AQ3, CUL2, PO1	Offer, along with the rental of bicycles or scooters, helmets, and other protective materials at the docks. Offer educational programs for beginners to learn best practices for moving around the city.	▪ Increase confidence and safety in the use of soft modes transport and increase awareness of how these types of transport can coexist with cars and pedestrians.	▪ Micromobility companies ▪ Urban mobility associations

6 Managerial implications

Considering the managerial implications of our study, we can provide several tangible guidelines for new business models. While many business models were forced to adapt to the changes caused by COVID-19, they also had opportunities to learn lessons from this mandatory adaptation. Companies should now have a better understanding of the current trends regarding the COVID-19 pandemic, mobility, sustainability, and technological innovation topics that are promising for the mobility sector and prioritize these trends to develop new services.

The points considered as business implications resulted from data collection in qualitative research later combined with a literature review. The first that stands out is to reap the benefits of new technologies for new mobility products and services development. Through interoperable systems integration, it would be possible to create a data communication network for citizens and the various business partners involved. This demand meets the growing trends of intense processes and services digitalization and the customers' autonomy towards these services. The second point indicates the challenges of mobility and urban planning: the need to overcome the cultural and physical barriers built by past car-centric strategies, align the vision of the different municipalities so that together they can work on long-term planning to achieve a real modal change. The key message of this topic is the extreme necessity of different actors and stakeholders' involvement, such as transport companies, urban planners, technology companies, and the citizens themselves, so the problems can be approached from different perspectives. The third aspect in the managerial implications involves initiatives to move forward with carbon neutrality. In this topic, two points are considered: promote public awareness together with the development of new policies and investments to combat the climate crisis. The second point concerns the monitoring of energy transition initiatives that Portugal has been leading and how it can be advantageous to envision future projects. The last managerial implication focuses on service development in a hybrid context. In a context of constant change, in which services need to be prepared to adapt to new environmental, sanitary, and technological strategies, businesses can adopt disruptive ways to modify or create their services, as well as more conservative ways, depending on the need and vision of each business. For this, service design can be adopted for analyzing the network that involves the business and adopting tools to leverage innovative ideas.

6.1 Reaping the benefits of new technologies

The digitalization of the daily routine and work processes were accelerated by the pandemic. People started working and studying from home and shopping and other tasks online. This brings evidence that people have been becoming more autonomous. The interoperability is taken as one of the main strategies to access comprehensive information from different operators and providers about the citizens' behaviors, needs, mobility patterns, transportation performance, and help municipalities plan in a more efficient way the urban space and the transport services based on citizen's needs. Promising technologies such as 5G, big data, artificial intelligence, automation, blockchain, IoT are part of a scenario for the future in which mobility becomes more digital, smart, autonomous, and intermodal.

With that said, we suggest the following initiatives:

- Implementation of new systems that are capable of exchanging information with business partners. It means that it is important to have **defined interoperability and data exchange standards for urban intelligence platforms** that streamline and accelerate the integration of solutions and transparency in the relationship between stakeholders, namely in the quality of service provided to citizens.

- **Use the combination of blockchain, big data, artificial intelligence and IoT** to get transparent information about the urban space and provide personalized experiences, like customized travel based on different variables such as security, time, price, comfort, security, sustainability, and occupancy level to avoid agglomerations.
- Combine a **data-driven approach with behavioral sciences consultants**, so that businesses and municipalities can benefit from a citizen segmentation, by predicting their needs and offering additional services beyond the mobility.
- Offer intelligent **self-services capable of predictive scenarios** and plan commuting, such as door-to-door travels, where payment and choice of means of transport is done in an automated way, considering external and internal factors of the user's life.
- With all these data exchanges, business partners need to pay attention and develop data **privacy policies to ensure transparency**, security, and data privacy control.

6.2 Addressing mobility and urban planning challenges

The current challenges of mobility and urban planning go through the disconnection of a shared vision between municipalities, the lack of connection between the time demand that disruptive urban planning needs to have in relation to political cycles, the car-centric vision in which cities were built, and therefore, generated cultural and physical barriers to other mobility modes. The lack of a data-driven approach to define better planning for the urban space and transportation and finally, because of the difficulty of planning urban spaces in constant expansion. In this topic, it is necessary to emphasize the need for partnerships with municipalities, transport companies, and technology companies since urban planning, which involves urban mobility, is carried out by different actors and stakeholders:

- Promoting urban, suburban, and interurban intramodality by **strengthening the availability of alternative transport modes to private cars**. This can be done through the provision of docks in residential environments, far from the centers, which can connect the citizen to a station. In addition, there are business opportunities around the Demand-Responsive transport (DRT) provision that could fill this gap to connect a person far from an urban center or station.
- Businesses can help the city to promote the citizen participation both in communicating **political and legal initiatives related to mobility**, and in **collecting data from citizens** through digital surveys. Both parties, companies, and municipalities, can benefit from potential innovations and co-creation cycles with the population. This can mitigate the problem of the individual interests of municipalities with initiatives that may not make sense for the citizen or for urban planning goals focused on sustainability. In addition, they can be a **powerful feedback tool for new experiments** in the city. However, it is important to consider the **inclusiveness** and **accessibility** of all citizens, the alignment of objectives, and the alignment between citizens' expectations and the decisions made.
- Increase the sense of safety and security for the walking and cycling users. This can be mitigated through the **investment on physical infrastructure** by developing cycling and walking corridors/lanes, and with business proposing a technological approach through the application of sensors in some urban areas, bicycles and scooters that could prevent eventual accidents or avoid risky areas. In addition, a cultural transformation

work involving citizens to **create hierarchical protection of the different modes**: pedestrian, bicycle, motorcycle, public transport, and automobile can be complementary initiatives regarding the mentioned ones.

- Businesses can help transportation companies, especially bus companies to **evaluate the level of accessibility for elderly citizens** with reduced mobility and offer design of solutions that make this **transportation modes more inclusive**. Other solutions for citizens with reduced mobility are necessary, for instance the **adoption of an on-demand business** can be a solution to reach more people with fewer resources, providing a shared fleet of different entities, crossed with other private operators.
- Ensure that **regulations are adapted** in relation to the security of users of different modes of transport, data management and privacy, interoperability, connectivity, and cybersecurity.

6.3 Moving forward with carbon neutrality

Awareness

Despite the growing concern about carbon neutrality and the environment, the population's awareness still needs to increase so that, together with new policies and investments focused on combating the climate crisis, carbon neutrality is achieved. For this, some initiatives can be taken to create more awareness among the population:

- **Companies can and must share responsibility** for reducing emissions with their employees. Offering benefits and vouchers for the use of more sustainable transport can be a factor of **great influence on people's behavior** and can bring a great positive impact on the environment.
- Providing people with information about the **emissions footprint** can influence them in their decision-making process about which mode of transport to choose or how far they will live, which directly impacts their level of commuting. In this, the technology can be adopted in applications such as MaaS, to understand **which means of transport are less polluting**. And Walk Score applications and platforms that help people understand which neighborhoods or cities offer better **commuting conditions** to access various services and modes of transport.
- **Cities and municipalities can promote tools that help citizens to visualize the emission rate**, assess progress against SDGs, using data science. For instance, the AYR platform², developed by CEiiA, is already an important tool that performs this function of quantifying CO2 emissions, and as a benefit it rewards AYR credits crypto tokens to be used in future rides and goods, bringing the positive effect of sustainable behaviors, and enabling the sustainability transaction. More projects complementary to this can be developed in this sense, giving the importance **to the need for a good data collection infrastructure**, as well as its analysis.

Energy transition

The Portuguese government investment have been focusing on supporting the decarbonization of road, rail, and public transport. In 2020, the Portuguese government enacted three plans to outline the energy transition strategy in the following of the

² AYR Platform, <https://weayr.com/#/home>. Accessed July 4, 2022.

COVID-19 pandemic. They are the National Energy and Climate Plan 2030³, the National Hydrogen Strategy⁴ and the Global Review of the Natural Gas Law⁵, which sets out the conditions for implementing the hydrogen strategy. The country's intention is to create conditions for the use of an energy mix based on renewable sources. This hybridization consists in the use of solar, hydrogen, hydroelectric and wind energy. Taking it into account, the following initiatives can be considered:

- **Review products and services energy sources** to follow the Portugal's vision about the energy transition.
- Understand how the new products can take advantage of the new energy resources. Moreover, **how the development of innovative products and services can leverage the energy transition process**. For example, the implementation of a charging network for electric cars in Portugal in 2009 was a trigger and an important contribution to accelerate the energy transition ⁶.
- **Make partnerships with renewable energy providers** to develop an energy storage system that can dynamically transfer clean energy to different vehicles, whether buses, cars, bicycles, scooters.
- **Understand how the batteries can be reused or recycled**, as it is still uncertain how the growth in the use of different types of batteries can be discarded and recycled.

6.4 Developing services in a hybrid context

While companies need to ensure that the development of new business models is customer-centric, recognizing the importance of understanding the role of customers in the service encounter: business managers also need to plan and develop new business models based on the entire network, to understand all the service encounters, since customers are increasingly connected with other technological services and multiple devices. (Cambra-Fierro et al., 2022)

Firms and designers need to recognize the multiplicity of social practices, processes, cultural context, social norms, beliefs, symbols, and the co-construction of context by transformative changes. Some changes were object of study in this dissertation. COVID-19 brought a new perspective in several industries and had impacted the way we live today. The climate crisis also has been shaping how the mobility will work in the cities to reduce carbon emissions through new environmental policies. Technological advances, the digitization of processes and Industry 4.0 will also have disruptive effects on mobility and cities. With this in mind, the businesses need to make constant exercises of zooming in and zooming out to develop new business models, avoiding risks of providing products and services that are not adaptable to new realities that are in constant change. For managers, the ecosystem and system analysis combined with service design approaches can leverage insights and a deeper understanding of the complex context in which it operates (Koskela-Huotari et al., 2021).

³ Resolution of the Council of Ministers No 53/2020, see <https://dre.pt/web/guest/pesquisa/-/search/137618093/details/normal?q=pnec+2030> (in Portuguese), accessed 17 June 2022. Most of the data used in section 1. *Energy Transition in Portugal: status* is available in the National Plan Energy and Climate 2030.

⁴ Resolution of the Council of Ministers No 63/2020, see <https://dre.pt/web/guest/pesquisa/-/search/140346286/details/normal?q=hidrog%C3%A9nio+estrat%C3%A9gia> (in Portuguese), accessed 17 June 2022.

⁵ Decree-Law No 62/2020, see <https://dre.pt/web/guest/pesquisa/-/search/141377978/details/normal?l=1> (in Portuguese); for more information in English, see <https://dre.pt/web/en/home/-/contents/141377978/details/normal>, accessed 25 May 2021.

⁶ Entrevista a Luís Reis, Centro para a Excelência e Inovação na Indústria Automóvel. <https://www.industriaambiente.pt/noticias/entrevista-a-luis-reis-ceia/>, accessed July 4, 2022.

7 Conclusion and future research

The present study provides an understanding of mobility patterns during the pandemic, and the experience of citizens using different types of transport before and during COVID-19 in Porto city. This approach allowed us to conclude how the pandemic context has become part of our routine, and how we will have to be prepared to live in this hybrid world, where new times require new approaches, solutions, and constant adaptations. To develop this study, it was adopted qualitative research with experts and decision-makers in the mobility area to capture their perception of the changes caused by the pandemic period, and what would be the main trends in sustainability and technology that could become relevant in new urban mobility business models.

Considering the limitations of the work developed, the study did not involve interactions with the stakeholders making it necessary that, in the future, this should be part of the projects roadmap to validate the strategies of involvement, as well as the proposed solutions. This project brought the perspective of experts and people involved in the topic of mobility in different ways. Even though they are also citizens and users of the various types of transport in the city of Porto, it is also necessary to extend the qualitative research to citizens who are not involved in the topic, but who use the mobility services available in the city. Interviews and ethnographic research can be tools for a better understanding of behavior patterns regarding the various types of urban mobility. Another aspect to be considered in future research is the understanding of value co-creation at all levels of the ecosystem and using service design approaches to visualize and analyze the multiple levels of new services to be created.

Regarding the change in mobility patterns, this study concludes that there was a **decrease in the use of public transport** due to remote working and the fear of contamination. Despite this, opportunities for the use of soft transportation stood out in this period, as there was a growth in the circulation of bicycles and scooters to avoid agglomerations, and there was also an incentive from the government with the construction of bike lanes, and through the subsidy for the purchase of bicycles and electric scooters. At the same time, there was a **significant return in the use of private vehicles** in this period, causing traffic to return to levels like pre-pandemic periods. From here, some hypotheses were raised for future studies that should seek to understand whether people who started using bicycles and scooters at some point migrated to private vehicles and why.

This study also concluded that in addition to the social and economic impacts due to the pandemic, there was an **increasing digitization of processes**, both in the means of validating ticketing for transport as well as for the increasing demand of electronic commerce, and remote working. These transformations and advances in technology enable the emergence of a new always-connected environment, where customers formulate their experiences in a more personalized and autonomous way (Ostrom et al., 2015). This fact is intrinsically linked to the trends of urban mobility, which, to keep up with the smart service shifts, needs to undergo a more disruptive transformation in terms of data communication so that the experience is increasingly shaped to the citizens' needs and better planned by the transport companies and municipalities. Also, **technology can be one of the main allies to improve transport efficiency**, reduce dependence on car ownerships and promote multimodal offerings. New business models can accelerate the reduction of owned vehicles, such as communities sharing ownership with shared use, bearing in mind that only true alternatives to individual transport will accelerate the process of change. For this, the development of interoperable systems that would enable the creation of efficient MaaS would be necessary to offer a personalized experience and, at the same time, promote emission reduction using shared vehicles and micromobility. However, as mentioned in this study, there are still many data infrastructure and

policy barriers for interoperability to be a reality in urban mobility. The **bureaucracy between public and private transport operators** and the resistance on the part of these two spheres to share a more transparent relationship are barriers to be overcome so that there is a services' integration.

The adoption of service design in this project involves **understanding the service ecosystem** and its stakeholders potentially involved, directly or indirectly, in the new business models based on the insights collected in the interviews and literature review. Another tool chosen to visually represent the comparison between the journeys of using mobility services in a pre-pandemic period and during a pandemic was the customer journeys, representing the main phases, user actions and touchpoints for each type of transport (bus, rail transport and shared micromobility). Given the pattern of barriers mentioned in the qualitative research, the addition of these barriers to each stage and action of the customer journey was also considered.

As in the ECO-SD method (Sierra-Pérez et al., 2021), these **barriers were categorized and used to address new proposals for experience improvements**, most of which involve greater integration between transport, support for digitalization and personalization of services, to stimulate the use of alternative transport modes to the private car and consequently lead to a reduction in carbon emissions.

In addition to the proposals focused on the experience of existing mobility services, managerial implications were also formulated in this study. These managerial implications aim is list recommendations for the business when thinking about innovating or creating a new business model. In the managerial implications, it is suggested that promising technologies should be integrated into mobility services, the challenges of mobility and urban planning in various aspects such as citizen participation, in the process of evaluating and reflecting on initiatives and developments, and the need to make partnerships between municipalities and transport companies. Another important point highlighted in these implications is the promotion of awareness in the population regarding environmental sensitivity to seek carbon neutrality, as well as, taking advantage of the processes of energy transition that Portugal has included in its programs. Finally, the recommendations bring up the importance of adopting the customer centric view, but also considering the entire network of services, and therefore having a vision of the ecosystem of services and their conflicts and alignments.

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APPENDIX A: Informed Consent

TERMO DE CONSENTIMENTO

Caro Participante,

Solicito a sua participação num estudo de investigação que decorre no âmbito do Mestrado de Engenharia de Serviços e Gestão da Universidade do Porto. O objetivo da investigação é genericamente perceber as relações dos serviços de mobilidade e como estes influenciam e serão influenciados em um cenário pós-covid. A sua participação neste trabalho é fundamental e neste sentido gostava de contar com o seu consentimento para que lhe possa fazer uma entrevista semi-estruturada, cujos resultados serão devidamente integrados na investigação. As respostas dadas por si serão estritamente confidenciais, e poderá desistir da entrevista a qualquer momento uma vez que a sua participação é voluntária. '

Tendo em conta que a entrevista será gravada, peço o seu consentimento para a gravação de áudio e/ou vídeo da mesma, uma vez que facilita o trabalho de transcrição da entrevista. No final de todo o trabalho de investigação todo o material gravado será destruído a fim de preservar o anonimato e confidencialidade do material.

Atenciosamente,

Data: _____ Nome do voluntário: _____

ESTE DOCUMENTO É FEITO EM DUPLICADO: UM PARA O PARTICIPANTE E OUTRO PARA O INVESTIGADO

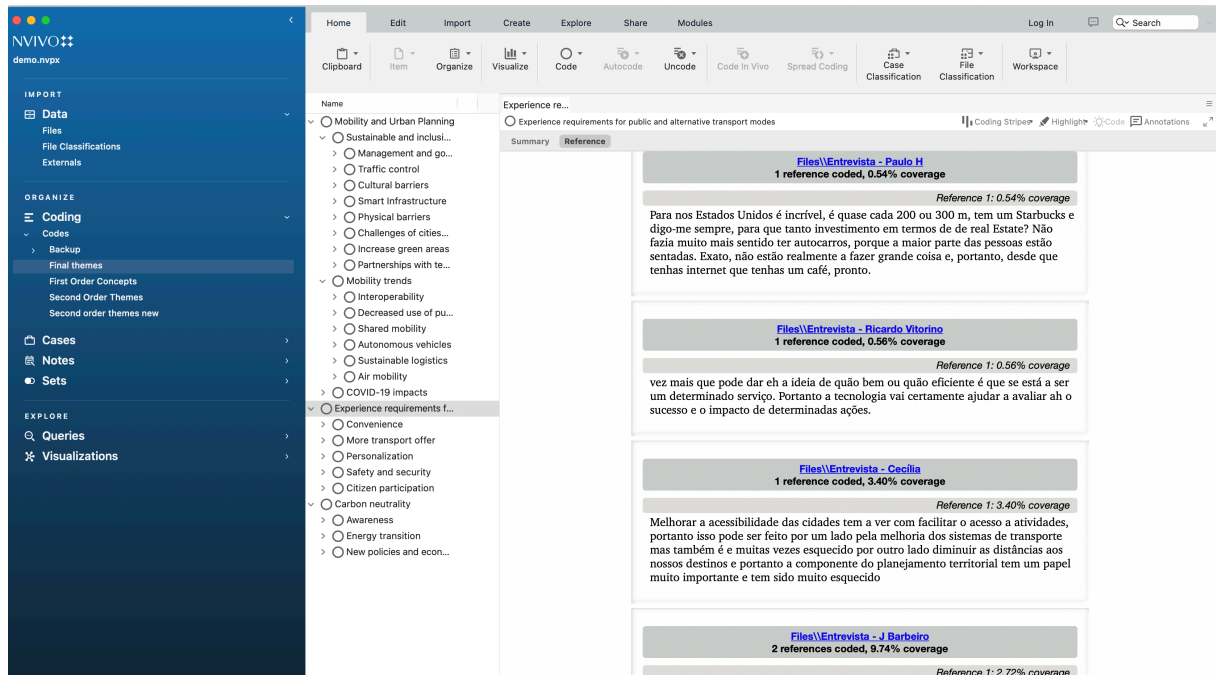
APPENDIX B: Discussion Guide

Discussion guide

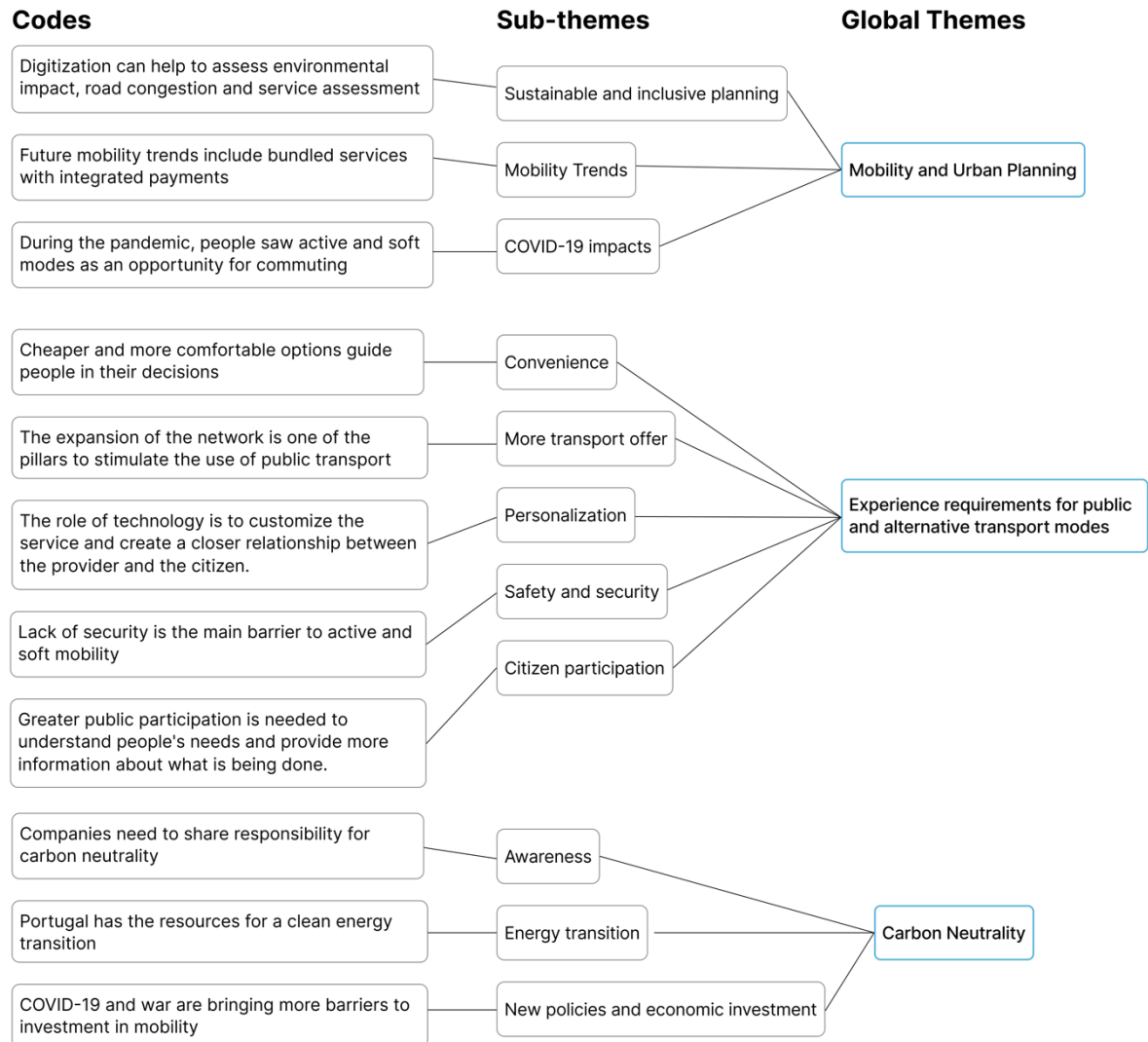
- Qual o seu histórico com o tópico da mobilidade? Como começou?
- Quais os comportamentos diários, em termos gerais, que, na sua opinião, mais se alteraram com a pandemia?
- Na sua opinião, quais os principais impactos da pandemia no setor da mobilidade urbana e interurbana?
- Que novas formas de uso e interação com os serviços e produtos de mobilidade enxerga no futuro?
- Que papel pode ter a tecnologia no desenvolvimento de novos modelos de negócio, serviços e produtos de mobilidade?
- Como vê a procura da neutralidade carbónica? Acha que a neutralidade do carbono pode ser conseguida de forma construtiva?
- Quais os 3 fatores principais que, na sua opinião, poderiam potenciar os sistemas e serviços públicos de mobilidade?
- Quais as principais barreiras à mobilidade ativa e suave nas cidades? O que mudaria nas cidades para promover estes modos de deslocação?
- Você me indicaria referências ou pessoas que possam ajudar com os tópicos que levantei nesta conversa?
- Existe algo relevante que não falamos nesta conversa que você gostaria de pontuar?

APPENDIX C: NVivo Screenshot

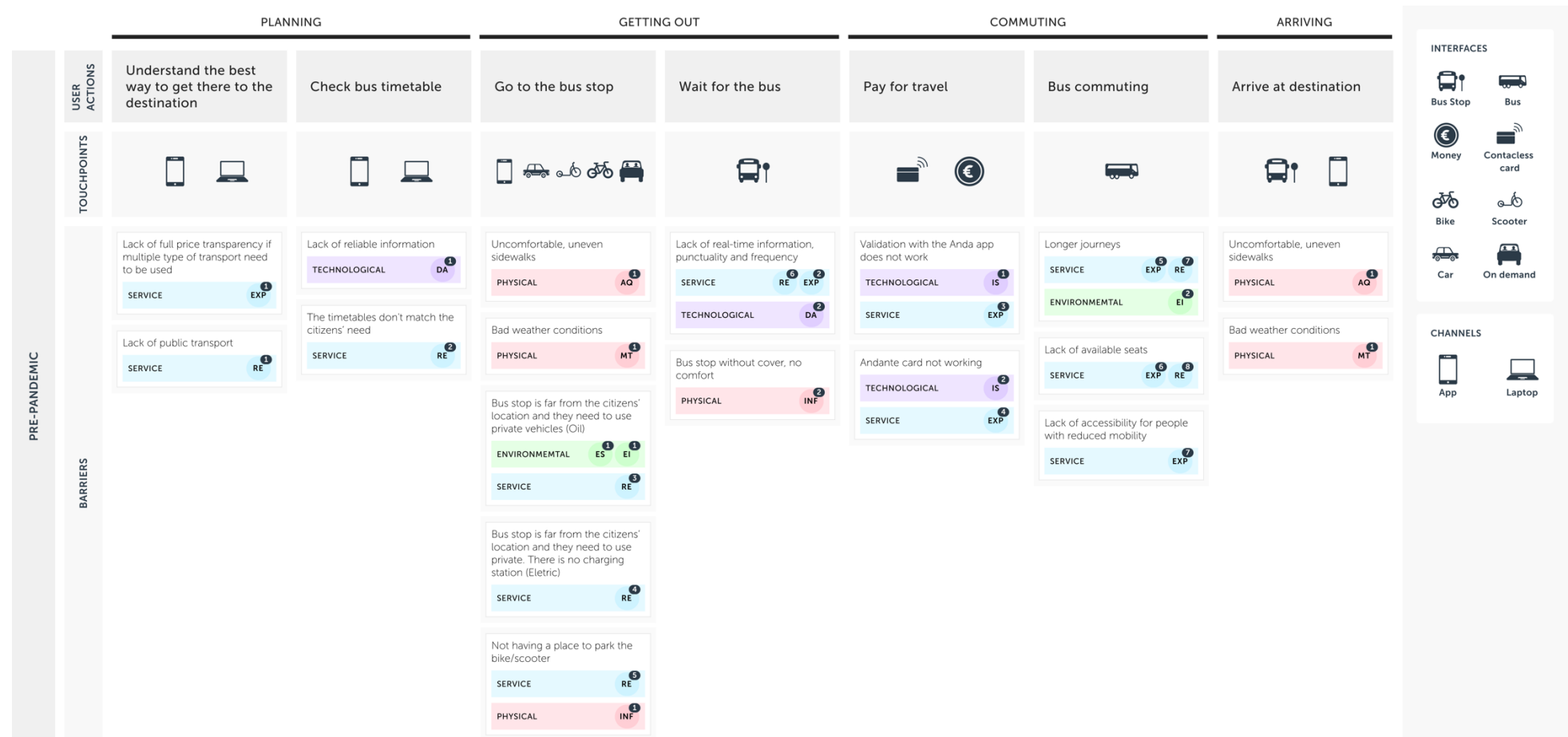
261 primary codes, 11 sub-themes, 3 global themes



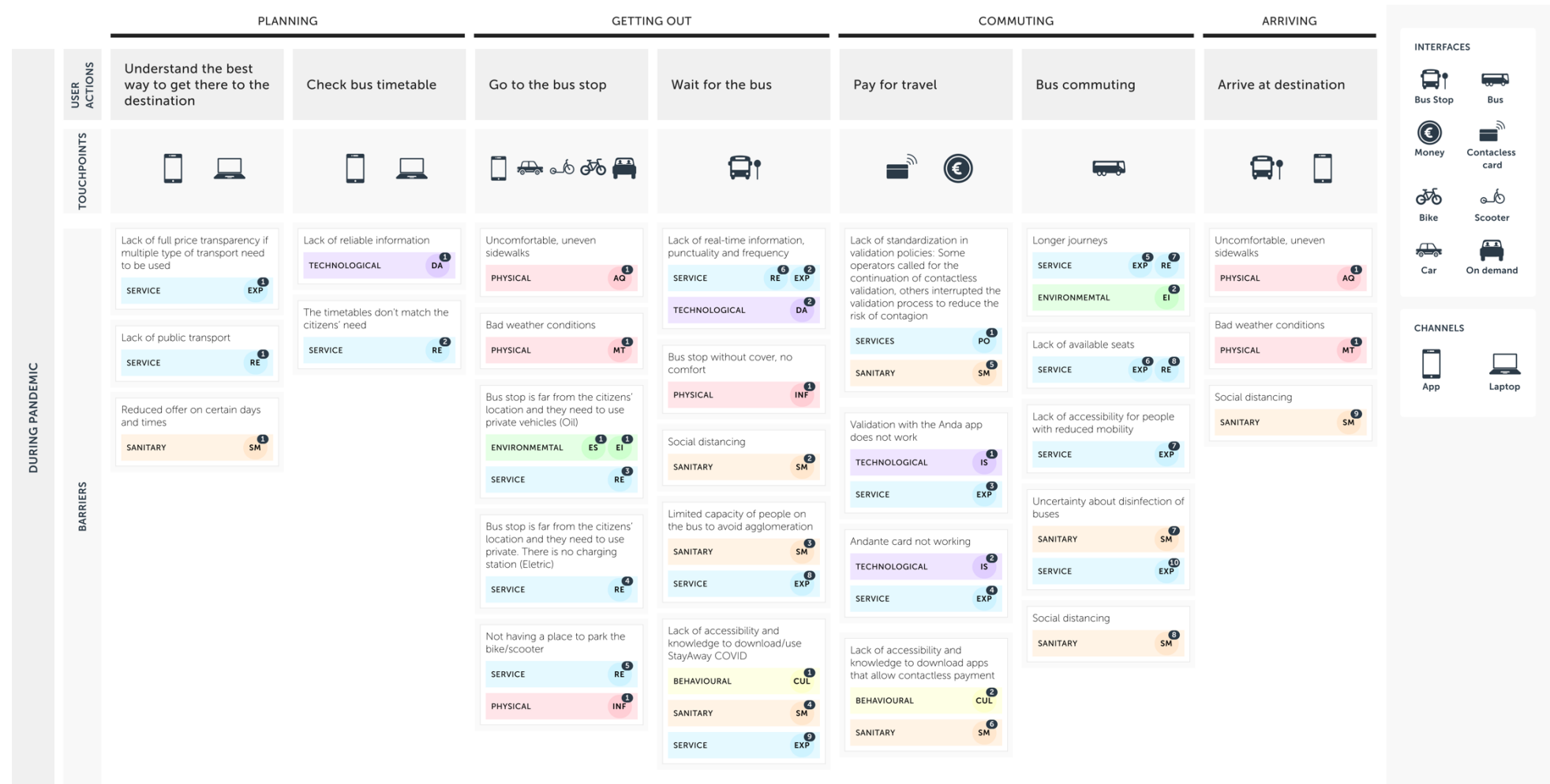
APPENDIX D: Example of categorization process



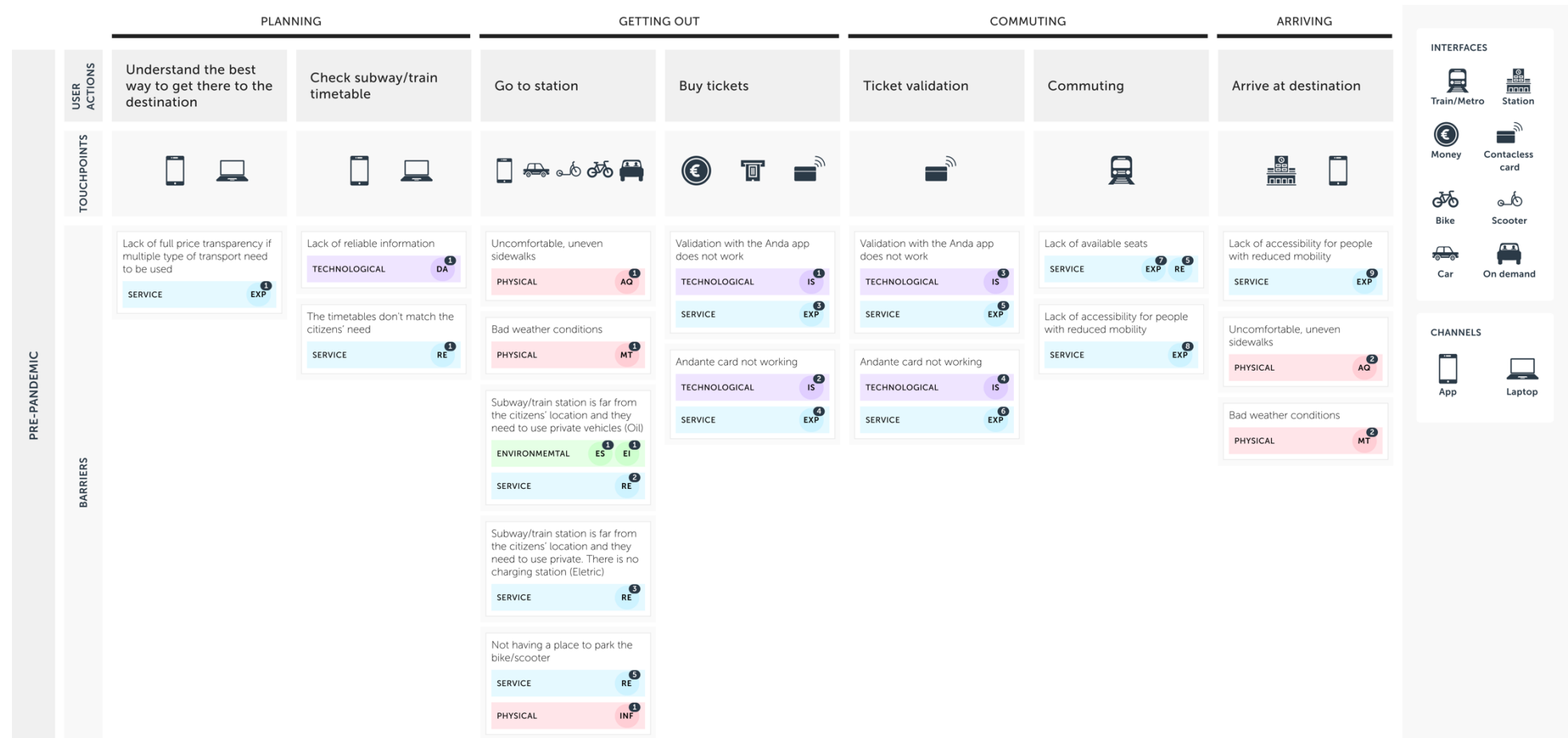
APPENDIX E: Citizen's journey in using buses before pandemic



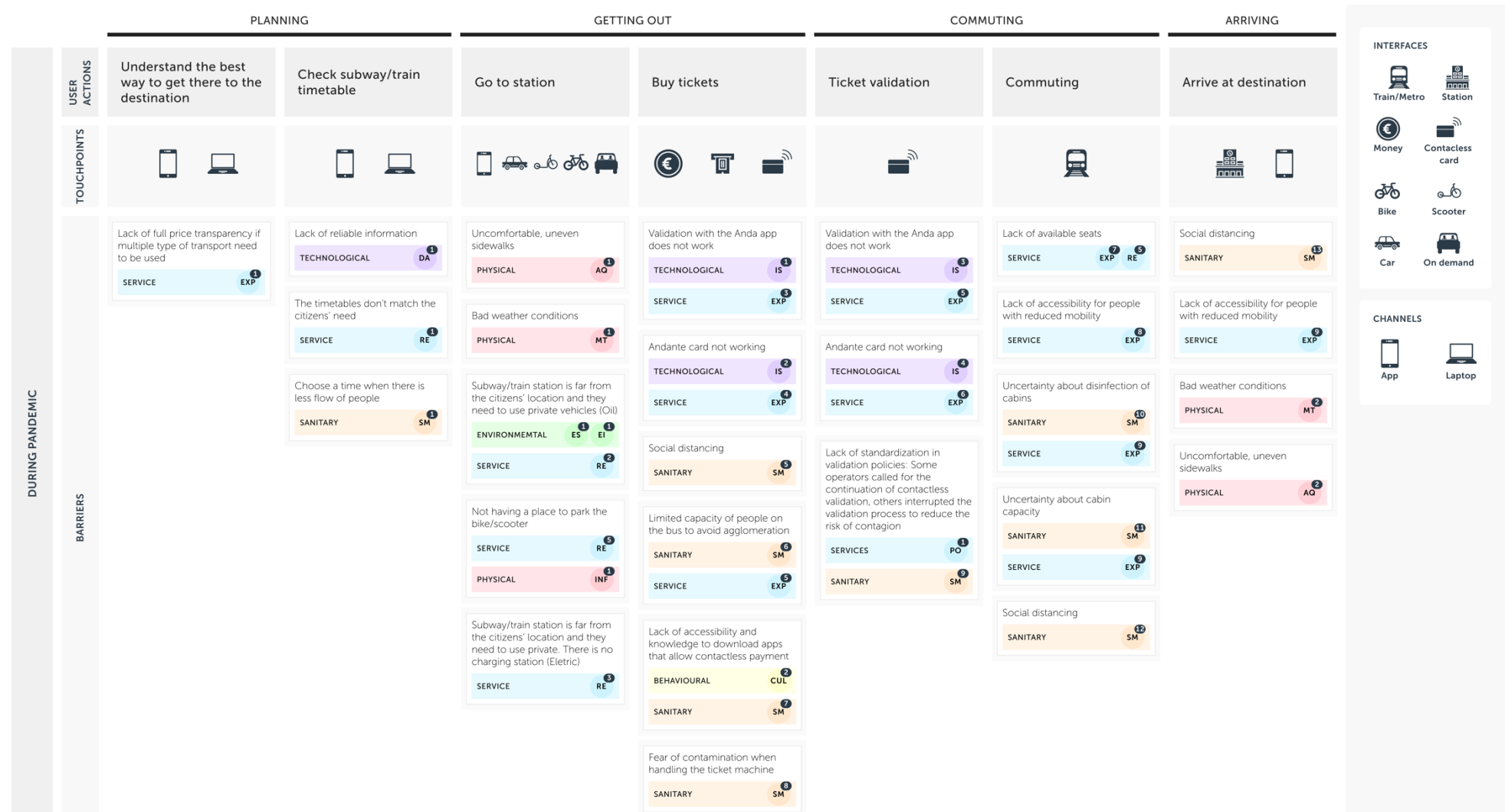
APPENDIX F: Citizen's journey in using buses during pandemic



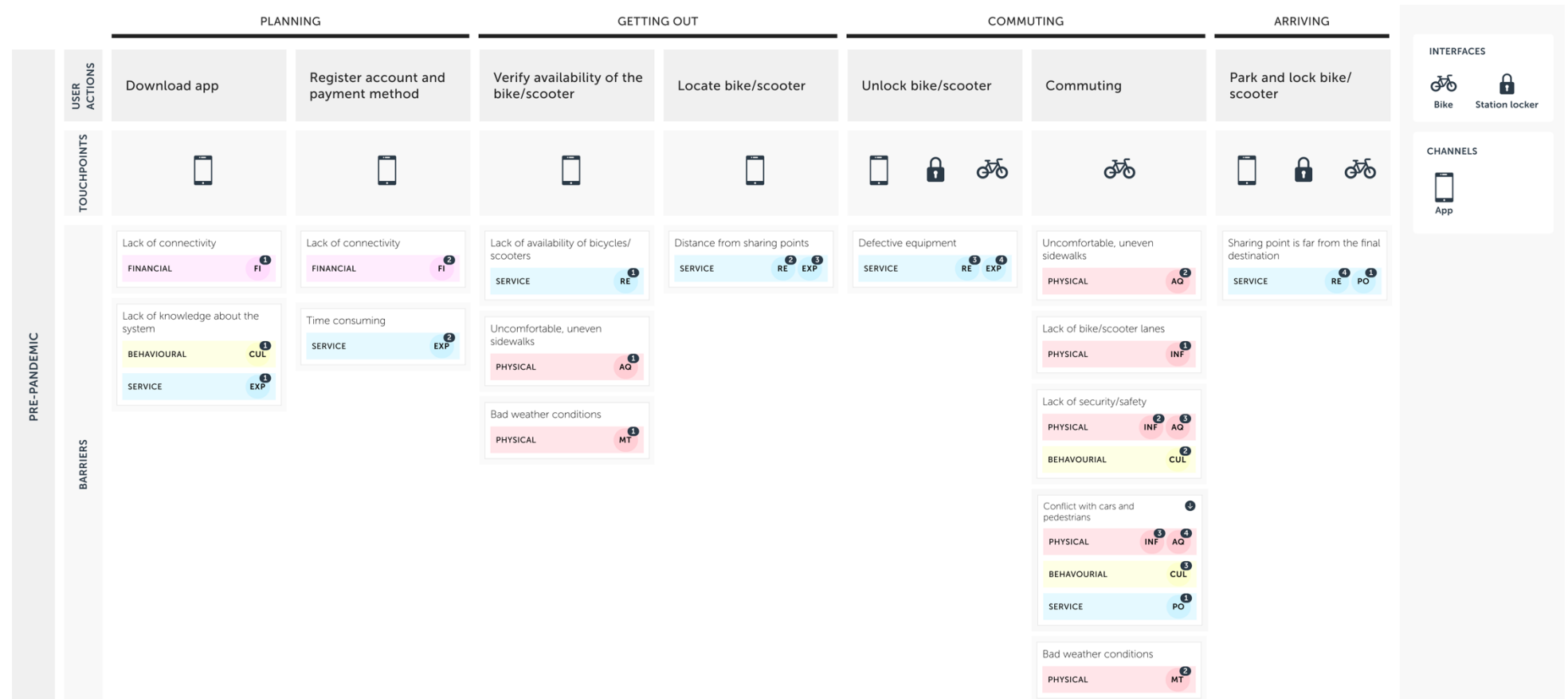
APPENDIX G: Citizen's journey in using railway transport before pandemic



APPENDIX H: Citizen's journey in using railway transport during pandemic



APPENDIX I: Citizen's journey in using micro-mobility before pandemic



APPENDIX J: Citizen's journey in using micromobility during pandemic

