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Tjark Gall. Scenario-based design of people-centred mobility solutions for urban systems. Architecture, space management. Université Paris-Saclay, 2023. English. NNT : 2023UPAST182 . tel-04400579

HAL Id: tel-04400579

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Scenario-based design of people-centred mobility solutions for urban systems

*Concevoir des solutions de mobilité centrées
sur les personnes à base de scénarios
pour les systèmes urbains*

Thèse de doctorat de l'université Paris-Saclay

École doctorale n°573 : interfaces : matériaux, systèmes, usages (INTERFACES)
Spécialité de doctorat : Ingénierie des Systèmes Complexes
Graduate School : Sciences de l'ingénierie et des systèmes. Référent : CentraleSupélec

Thèse préparée dans le Laboratoire Génie Industriel (Université Paris-Saclay, CentraleSupélec), sous la direction de **Flore VALLET**, Enseignante-chercheuse, HDR, Léonard de Vinci Pôle Universitaire et CentraleSupélec, la co-direction de **Bernard YANNOU**, Professeur, CentraleSupélec, et le co-encadrement de **Sylvie DOUZOU**, Chercheuse sénior, EDF R&D.

Thèse soutenue à Paris-Saclay, le 24 novembre 2023, par

Tjark GALL

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Title: Scenario-based design of people-centred mobility solutions for urban systems

Keywords: Urban systems, people-centred design, scenarios, urban mobility

Abstract: Seven out of ten people will be living in cities by 2050. Mobility is crucial for them to access work, education, and urban services. This access is unequally distributed while responsible for 8% of global emissions. To mitigate this, various *mobility solutions* are designed. However, underlying assumptions are situated in complex and volatile contexts, including future uncertainties such as *heterogeneous and changing behaviours of people*. While predicting what will happen remains impossible, methods exist that integrate *future uncertainties*. To date, these are resource-intensive and rarely used. We tackle this by asking, 'how can design processes of people-centred mobility solutions for future urban systems be supported?' Using a mixed-method approach, including nine workshops and 35 interviews with experts, we propose a *scenario-based design support framework*. The framework comprises a model of *urban mobility systems* (UMS) in three layers: *People, infrastructures, and services*, supported by an updated *futures representation* to foster prospective co-creation. Applying the framework to Paris and Cairo, we make three other contributions:

(1) A *scenario localisation method* first tackles the adaptation of scenarios to local conditions. The structured approach permits selecting existing scenarios by using a checklist before localising and enhancing them via iterative steps resulting from the UMS layers. (2) Focusing on the people layer, the *future synthetic population generation method* uses scenarios and data-driven personas to create a set of future urbanite models. This method permits the structured integration of future uncertainty with focus on socio-demographic trends in quantitative methods such as activity-based mobility modelling. (3) Thirdly, an *urban impact assessment tool* allows to assess the impacts of potential mobility interventions across indicators and scenarios with focus on heterogeneous impacts on diverse people in a collaborative setting. Throughout each case study, reproducibility, use of open data, and open-source tools were paramount. We showed that the proposed framework and contributions to a larger toolbox for UMS solution design can benefit the design of urban mobility solutions that are more 'futureproof' and people-centred.

Titre : Concevoir des solutions de mobilité centrées sur les personnes à base de scénarios pour les systèmes urbains

Mots clés : Systèmes urbains, conception centrée sur les personnes, scénarios, mobilité urbaine

Résumé : Sept personnes sur dix vivront en ville d'ici 2050. La mobilité est cruciale pour accéder au travail, à l'éducation et aux services urbains. Cet accès à la mobilité est inégalement réparti tout en étant responsable de 8 % des émissions mondiales. Diverses *solutions de mobilité* sont conçues pour atténuer cela. Cependant, les hypothèses de conception s'inscrivent dans des contextes complexes et volatiles, comprenant des *incertitudes futures* telles que des comportements de citoyens hétérogènes et évolutifs. Même si la prédiction de ce qui va se passer reste impossible, il existe des méthodes qui *intègrent les incertitudes futures*. À ce jour, celles-ci sont gourmandes en ressources et rarement utilisées. Nous abordons ce problème en nous demandant : *Comment accompagner les processus de conception de solutions de mobilité centrées sur les personnes pour les futurs systèmes urbains ?* En utilisant une approche de recherche mixte, comprenant neuf ateliers et 35 entretiens avec des experts, nous proposons un cadre d'aide à la conception basé sur des scénarios. Le cadre comprend un modèle de systèmes de mobilité urbaine (Urban Mobility Systems ou UMS) à trois couches : *personnes, infrastructures et services*, ainsi qu'une représentation des futurs, mise à jour pour favoriser la co-création prospective. En appliquant ce cadre à la mobilité de Paris et du Caire, nous apportons trois autres contributions :

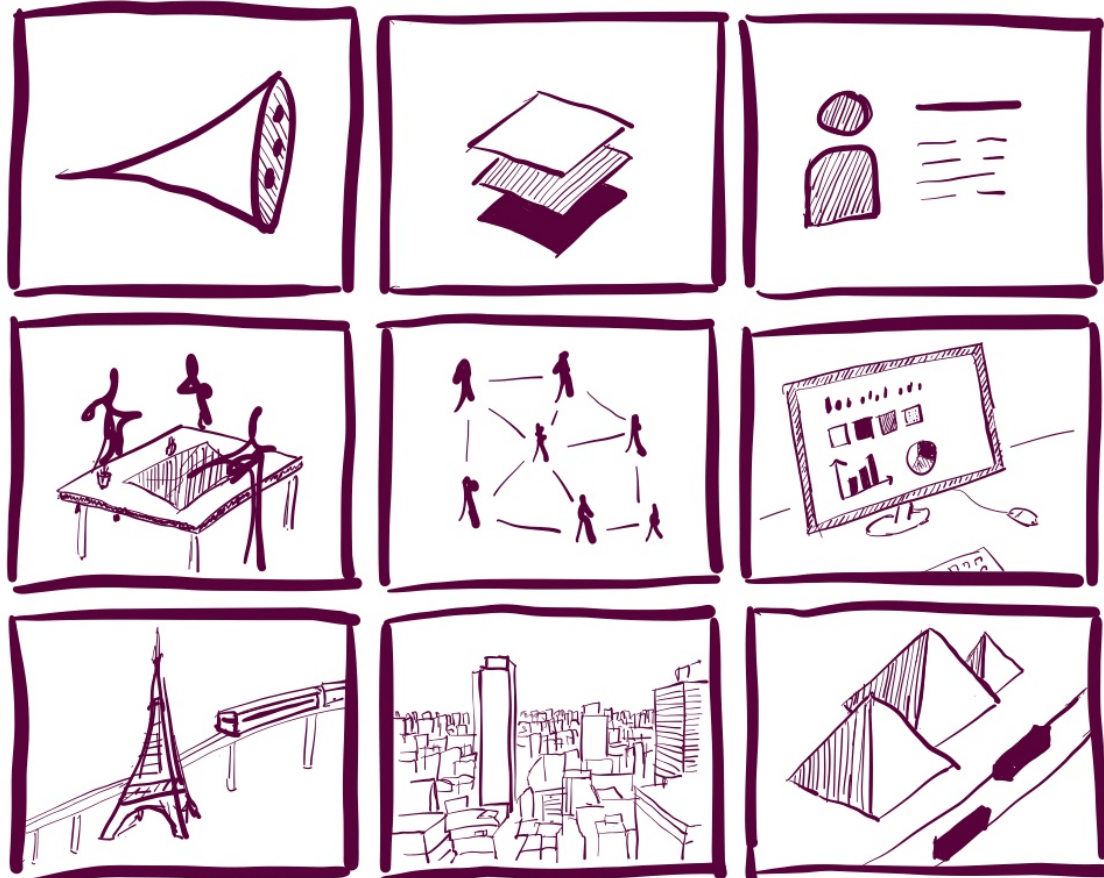
(1) Une *méthode de localisation de scénarios* qui aborde l'adaptation des scénarios aux conditions locales. La structuration de l'approche permet de sélectionner des scénarios existants à l'aide d'une liste de contrôle avant de localiser ceux-ci et de les enrichir par des étapes itératives issues des couches d'UMS. (2) En se concentrant sur la couche des personnes, la *méthode de génération d'une future population synthétique* utilise des scénarios et des personas basés sur des données pour modéliser un ensemble de futurs citoyens. Cette méthode permet l'intégration structurée de l'incertitude future en mettant l'accent sur les tendances socio-démographiques dans des méthodes quantitatives telles que la modélisation multi-agent de la mobilité. (3) Troisièmement, un *outil d'évaluation de l'impact urbain* permet d'évaluer les impacts des interventions potentielles en matière de mobilité à travers des indicateurs et des scénarios dans un cadre collaboratif. L'accent est mis sur la variation de ces impacts pour divers groupes de citoyens. Dans chaque étude de cas (Paris et le Caire), la reproductibilité, l'utilisation de données et d'outils ouverts sont primordiales. Nous avons montré que le cadre proposé et les contributions à une boîte à outils plus large au service de la conception de solutions UMS peuvent bénéficier à la création de solutions de mobilité urbaine davantage « à l'épreuve du temps » et centrées sur les personnes.

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Doctoral dissertation

SCENARIO-BASED DESIGN OF PEOPLE-CENTRED MOBILITY SOLUTIONS FOR URBAN SYSTEMS

By Tjark Gall, December 2023



Supervisory Team

Flore Vallet | Bernard Yannou | Sylvie Douzou

Version: v.03

AnthroPOLIS
HUMAN CENTERED MOBILITY

SystemX

CentraleSupélec

Citation:

Gall, T. (2023). Scenario-based design of people-centred mobility solutions for urban systems. Doctoral dissertation, University Paris-Saclay.

Important note

To cite this publication, please use the last version published on HAL (<https://hal.science>).

Funding

Supported by the French government under the 'France 2030' programme as part of the SystemX Technological Research Institute.

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ACKNOWLEDGEMENTS

My doctoral journey started to delve deeper into urban systems and learn methods that contribute to planning and designing them better. Now – more than at the start – the doctoral puzzle pieces start fitting those laid out over the past 12 years. My understanding of urban areas today – as limited as it remains – has been built by many. To everyone my deepest gratitude. I will try to pass it on and continue your paths. My thanks go to Adam Abdin, Ana Peric, Andreas und Britta Kerstingjohänner, Anja, Anna, Alessandro, Ayman, Bassem, Benjamin, Benoit*2, Bernd Ax, Brian, Cameron, Camille, Cedric, Christian, Christina Krafczyk, Christine, Diego, Didier Vancutsem, Dirk Ahlers, Dirk Neumann, Eliane, Elisa, Elise, Emilien, Emma, Emmanuel, Fawaz, Fabian, Federico, Felix Carreyre, François Cluzel, Francisco, Franck Marle, Gaby Kurth, Georges Herbrail, Ghada, Göran, Gustavo, Guilherme, Haifa, Icaro, Ismail Patel, 3*Jan, Jonas, Julia, Julian, Julien, Joseph, Kim, Malek Ben Ammar, Manon Eskenazi, Marc-Olivier, Mariana, Marija Jankovic, Martin Dubbeling, Martin Peschken, Maycon Sedrez, Max, Michele Tirico, Milena Ivkovic, Ndongwa, Neeanne, Nick, Noor, Olaf Mumm, Ouidad Benhlime, Pascal, Patrice Aknin, Patrick, Reza, Robert, 2*Robin, Rishi, Sarah, Simo, Sindi, Sophia, Sven, Thais, Thomas Machiels, Vanessa M. Carlow, Victor, Vivi, Wissal Sahel, Yann Briand, Yann Leroy, Yannick Perez, Yasmine, Yue Su, Zeynep Gunay, and all those I momentarily forgot.

Thank you for the support, Delphine, Corinne, Christèle, April (LGI), and Pauline (IRT), for dialogue and collaboration with friends and colleagues at ISOCARP, AESOP, and Urban AI, and the Bibliothèque Sainte-Geneviève where most of this was written.

Thank you to the representatives of the Anropolis Chair partners, workshop participants, and interviewees, the warm welcome by Nabil and Sherif at the American University in Cairo, and Hegazy, Melegy, Hazem, Ghada, Hend, Mariam, Merna, and Moataz at Transport for Cairo.

Thank you to the intermediate thesis committee members, Isabelle Nicolai and Jean-François Boujut, and the members of the jury for taking the time to review my work.

A big thank you to my colleagues at the Anropolis Chair with which I had the pleasure to collaborate: Flore, Sylvie, Mariana, Jakob, Sebastian, Tarek. A special thanks to the latter two for being patient during my simulation adventures.

À mes encadrants Flore Vallet, Sylvie Douzou et Bernard Yannou pour m'avoir accueilli, mis au défi, enseigné et soutenu continuellement : Merci beaucoup !

Danke Kirsten, Thole, Kristina, Reimar, Jutta, Renate, Hanna, Hans, Meinhard, für mitgegebene Werte, Respekt für unsere Umwelt und Mitmenschen, Eigenständigkeit und Hilfe wenn meine Pläne wieder einmal missglücken.

Finally, thank you to those who were at my side in the past – and to Clémence for being it today. Your support, flexibility, and comprehension has been and will remain central to everything I do. Every achievement is yours more than mine.

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SUMMARY

Le résumé étendu en français se trouve à l'Appendix AP.1.

Climate crises do transition continuously and faster than expected from a long-term fear to a lived reality. Scientific evidence clarifies the dominant role of humans therein since the beginning of the industrialisation until today. The majority of the now over eight billion people live in cities and create over two thirds of global emissions. Tendency rising. The key contributors are transport, housing, and energy, with urban mobility estimated at a global contribution of at least 8%. Added to the emissions are local pollution, highly unjust levels of access to opportunity, over 1.3 million traffic death and millions of serious injuries and increasing concerns of future access to resources such as oil or rare materials needed for battery electric vehicles. A plethora of conceptualised as well as tested solutions exist to reverse or at least attenuate these negative impacts and contribute to sustainability transitions of urban mobility systems globally. However, the processes to design and plan these systems and potentially embedded solutions are complexified by various factors. One of them is future uncertainty; the proven inability to forecast how people, technologies, cities, and urban systems will evolve.

This doctoral project, rooted in design sciences, started with the objective to develop *methodological contributions* to systematically respond to the socio-environmental challenges while integrating future uncertainties in the process. Or as formulated in the initial project outline, to 'develop a structured methodological approach to produce innovative mobility solutions in a territory.' Leading the task on *futures of urban life and mobility* at the Anthropolis Chair by Jakob Puchinger until 2022 and Flore Vallet thereafter and embedded in the Design Engineering team at the Laboratoire Génie Industriel of CentraleSupélec, University Paris-Saclay, the doctoral project evolved from a rich and collaborative process, including with the partners: The inter-council partnership Paris-Saclay, EDF, Engie, Groupe Renault, and Nokia Bell Labs. In the second half of the project, a research visit in Egypt enabled by the collaboration with the American University in Cairo and the research consultancy Transport for Cairo permitted an application and replication of developed methods in a heterogenous context representative of many of the aforementioned socio-environmental challenges. Originating from this context and stated problem, the overarching research question was set: *How can design processes of people-centred mobility solutions for future urban systems be supported?*

To find responses to this question, a mixed method, grounded theory approach was laid out that combined a case study approach applied to the two contexts with a range of 35 interviews, nine workshops, and other collaborative activities, as well as a couple of quantitative methods. This resulted in some contributions at the conceptual, meta-methodological stage, as well as more technical methods and tools. Two models are proposed for urban systems and futures respectively, as well as a joint model to work with urban mobility system futures. Subsequently, a set of three methods are proposed: *A scenario localisation method*, *a future synthetic populations' method*, and an *urban impact assessment tool*. The methodological framework, as well as the developed tools have been created and applied in the context of Paris to:

1. Define the urban mobility system of Paris, constituted of people, infrastructures, and services,

2. Localise archetypical scenarios in the French context,
3. Create a set of personas and synthetic populations of the future for each of the scenarios,
4. Create an online decision support platform as a second – possibly preceding – rapid assessment tool that integrates future uncertainty via scenarios, and
5. Apply an agent-based mobility simulation framework to the scenarios to evaluate the potential impact of shared automated electric vehicles in intermodal mobility service.

The main steps of system modelling, scenario localisation, scenario-based persona and synthetic population creation, and agent-based scenario simulations have been replicated to and validated in the context of Greater Cairo. In this case, the socio-environmental impacts of a bus rapid transit system on the ring road, improved walkability around mass transit stations, as well as simplified intermodality between public transport segments were tested.

On a methodological level, the two application case studies showed that the developed framework can contribute to the structured integration of uncertainties in the evaluation and, therefore, design processes of urban mobility systems or their components. On a thematic level, the application cases highlighted in Paris-Saclay the potential benefits of shared automatised electric vehicles across social, environmental, and economic dimensions. However, the impacts are highly heterogeneously distributed across 16 identified persona profiles and are outweighed by both the differences between scenarios resulting from socio-spatial changes, as well as anticipated technological vehicle efficiency gains. In the case of Cairo, the same overall observations could be made. However, the impacts of a mix of the tested interventions were especially significant for the future scenarios which anticipate ongoing sprawl and increase of the individual car ownership rate – a combination which can be considered as a more likely direction. This results in policy recommendations for less sprawl and constrained car ownership paired with a targeted mix of intervention strategies to amplify the use and uptake of sustainable and efficient mass transit.

To respond to the research question of how to support design processes of people-centred mobility solutions for future urban systems, we do not claim to have found a universal answer. However, we can confidently postulate that a mixed methods approach integrating scenarios, personas, and complex systems thinking in urban system design processes can contribute to better future preparedness and new methodological levers to integrated sustainability and people-centredness into design.

The results have been presented at seven international conferences, two national conferences, two young researchers' fora, one summer school, were enriched by the results of two co-supervised student projects, and resulted in nine peer reviewed papers, including two journal papers, a report contribution for UN-Habitat, and a lead-authored book on sustainable urban mobility futures in publication.

To summarise, the uncertainties of the future require structured and novel approaches to integrate them in design processes and methods. And while futures are the primary topic of this doctoral project, their relevance originates from the moment in which design decisions must be taken: *Today*.

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ACRONYMS + ABBREVIATIONS

A complementary glossary can be found in [Appendix AP.2](#) (p. 300).

AR	Assessment Report (referring to IPCC reports)
ASI	Avoid-Shift-Improve framework
AUC	American University in Cairo
AV	Autonomous/Automated Vehicles
BRT	Bus Rapid Transit
CAPMAS	Central Agency for Public Mobilisation and Statistics (Egypt)
CAS	Complex Adaptive System
CC	Creative Commons (creativecommons.org)
CDC	Centers for Disease Control and Prevention
CEDARE	Centre for Environment and Development for the Arab Region and Europe
CO₂	Carbon dioxide
CO_{2e}	CO ₂ equivalent
COP	Conference of the Parties, governing body of UN Climate Change Convention
CPS	Inter-council partnership Paris-Saclay (FR: Communauté d'agglomération Paris-Saclay)
DE	Density
DI	Diversity
EC	European Commission
EDF	Électricité de France
eMaaS	electric Mobility-as-a-Service
EMP	Mobility of people survey (FR: Enquête Mobilité des personnes)
EPA	Public Planning Establishment (FR: Établissements publics d'aménagement)
EPAPS	Public Planning Establishments Paris-Saclay
ERF	Economic Research Forum
EU	European Union
FNAU	National Federation of Urban Planning Agencies (FR: Fédération Nationale des Agences d'Urbanisme)
FSM	Future Scenario Method
FUA	Functional Urban Area
GDP	Gross Domestic Product
GDPR	General Data Protection Regulation
GHG	Greenhouse Gas
GIS	Geographic Information System
GIZ	German Development Agency (DE: Gesellschaft Internationaler Zusammenarbeit)
GOB	Google Open Buildings
GoE	Government of Egypt
GOPP	General Organization [sic] for Physical Planning
GPE	Grand Paris Express
GTFS	General Transit Feed Specification
ICED	International Conference on Engineering Design
IDF	Île-de-France
IDFM	Île-de-France Mobilities
IM	Intermodality
INSEE	National Institute of Statistics and Economic Studies (FR: Institut national de la statistique et des études économiques)
IPCC	International Panel on Climate Change
IRT	Institute of Technological Research (FR: Institute de Recherche Technologique)
ISOCARP	International Society of City and Regional Planners

ITF	International Transport Forum
JICA	Japan International Cooperation Agency
KPI	Key Performance Indicator
LEZ	Low Emission Zone
LFS	Labor Force Survey
LGI	Industrial Engineering Laboratory (FR: Laboratoire Génie Industriel)
LRT	Light Rail Transit
MaaS	Mobility-as-a-Service
MATSim	Multi-Agent Transport Simulation
MGP	Metropolis of Greater Paris (FR: Métropole du Grand Paris)
MLP	Multi-Level Perspective
NDC	Nationally Determined Contributions
NUA	New Urban Agenda
OD	Origin Destination
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OSM	Open Street Maps
PCD	People-Centred Design
PKM	Passenger kilometre
PP	Proto-Persona
PSS	Product-Service System
PT	Public Transport
R&D	Research and Development
RER	Regional Express Network (FR: Réseau Express Régional)
SAEV	Shared Automated Electric Vehicles
SDG	Sustainable Development Goal
SoS	System-of-Systems
SP	Synthetic Population
SPT	Social Practice Theory
STS	Socio-Technical System
SUMP	Sustainable Urban Mobility Plan
TD	Transition Driver
TFC	Transport for Cairo
TGV	High-speed Train (FR: Train à Grande Vitesse)
TI	Travel interviews
TOC	Table of Contents
TOD	Transit-Oriented Development
UA	Urban Areas
UITP	International Association of Public Transport (FR: Union Internationale des Transports Publics)
UM	Urban Mobility
UMS	Urban Mobility System
UMST	Urban Mobility System Transition
UN	United Nations
UN-Habitat	United Nations Human Settlements Programme
V2G	Vehicle-to-Grid (charging)
V2I	Vehicle-to-Infrastructure (communication)
V2V	Vehicle-to-Vehicle (communication)
WCED	World Commission on Environment and Development
WG	Working group

FOREWORD

The dissertation is written as a continuous story but integrates published or submitted articles. The references of used publications are listed below and clearly mentioned at the start of each chapter or section.

The dissertation is structured in six chapters. In the *First Chapter*, we introduce the research outline, including the context of the research project, the tackled problem, resulting research questions, and a short overview of the contributions. In the *Second Chapter*, we detail the background of the study. This refers primarily to the related research fields and larger connected developments, including sustainable urban development with zoom-in on greater Paris and Cairo, sustainable urban mobility, designing with uncertain futures, and people-centred approaches. Building on the background, the *Third Chapter* describes the research methodology. In the *Fourth Chapter*, we propose the first set of contributions related to designing future urban mobility systems via scenarios. This includes a scenario-based approach, a collaborative modelling of urban mobility systems, and linking scenarios and urban mobility systems to arrive at an applicable methodology to work strategically with alternative futures of urban mobility. This is followed by a deep dive into one of the three layers of the previously developed urban mobility system model in the *Fifth Chapter: People*. More specifically, we propose a method to design for future urbanites – referring to the urban population of the future. For this, we introduce a mixed-method approach combining qualitative and quantitative design and simulation methods. For the purposes of development, demonstration, and validation, these are applied to three application cases in the context of greater Paris and Cairo. Finally, the *Sixth Chapter* summarises the contributions, attempts to respond to the research questions, discusses the conducted work, and makes a set of recommendations for practice and future research. Complementary information is referenced throughout and provided in the *Annexes*, notably information on underlying data and conducted activities. The *Appendices* provide supplementary, stand-alone information, such as the French summary or a glossary on key terminology (Appendix AP.2). In case of gender-sensitive vocabulary (e.g., a user that takes *her* car) the feminine version is used consistently for ease of reading.

The following papers were produced during the doctoral project, are used in the dissertation, and have been published or are currently *pending*:

Journal papers

1. **Gall, T.**, Vallet, F., and Yannou, B. (2022) How to visualise futures studies concepts: Revision of the futures cone. *Futures*, 143/103024. <https://doi.org/10.1016/j.futures.2022.103024>
2. **Gall, T.**, Hörl, S., Vallet, F., and Yannou, B. (2023) Integrating future trends and uncertainties in people-centred urban mobility design via data-driven personas. *European Transport Research Review* [forthcoming]

Conference papers (peer-reviewed)

3. **Gall, T.**, Vallet, F., Ben Ammar, M., and Yannou, B. (2023) Designing solutions for uncertain futures: A checklist for choosing suitable scenarios. ICED23.
4. **Gall, T.**, Vallet, F., and Yannou, B. (2023) Comment concevoir des systèmes de mobilité urbaine pour les citoyens du futur ? *Épique* 07/2023.

5. **Gall, T.**, Chouaki, T., Vallet, F., and Yannou, B. (2023) Un cadre basé sur les scénarios du futur au service de la simulation multi-agents de la mobilité urbaine de demain. s.mart colloque.
6. Vallet, F., Hörl, S., and **Gall, T.** (2022) Matching Synthetic Populations with Personas: A Test Application for Urban Mobility. *Proceedings of the Design Society*, 2, 1795-1804. <https://doi.org/10.1017/pds.2022.182>
7. **Gall, T.**, Vallet, F., Douzou, S., and Yannou, B. (2021) Anticipate, Adjust, Adapt: Managing Sustainability Transitions through multiple Scenarios of Urban Mobility Futures. 49th European Transport Conference, online, Sept. 2021.
8. **Gall, T.**, Vallet, F., Douzou, S., and Yannou, B. (2021) Re-defining the System Boundaries of Human-Centred Design. *Proceedings of the Design Society*, pp. 2521-2530. <https://doi.org/10.1017/pds.2021.513>

Other conference papers

9. **Gall, T.**, Vallet, F., and Yannou, B. (2021) Co-Creating Sustainable Urban Futures: An initial Taxonomy of Methods and Tools. ISOCARP 56th World Planning Congress 'Post-Oil City – Planning for Urban Green Deals', Doha, Nov. 2021.
10. **Gall, T.** (2021) Working with multiple Scenarios: Revising the Futures Cone. Conference paper, AESOP YA Conference 2021 in Tirana, Albania, March 2021.

Other publications

11. **Gall, T.**, Vallet, F., Reyes, M., Hörl, S., Abdin, A., Chouaki, T., and Puchinger, J. (2023) Sustainable Urban Mobility Futures: Transdisciplinary Challenges, Trends, and Pathways for Sustainability Transitions. London: Palgrave Macmillan/Springer [in press]
12. **Gall, T.** and Allam, Z. (2022) Strategic foresight and futures thinking in urban development: Framing planning perspectives and decolonising urban futures, p. 10-19. In: Peric, A., Permezel, M., Stott, M., and Woo, A. *Future Cities Series: Practical planning guidance for innovative, resilient and inclusive cities of the future: Discussion paper 1*. Nairobi/The Hague: UN-Habitat and ISOCARP. Available at: <https://hal.archives-ouvertes.fr/hal-03832837/>

By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons.

United Nations Sustainable Development Goal 11.2

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1 INTRODUCTION

This chapter outlines the overall context, objective, and structure of the doctoral project. It starts by providing a brief background description and the initial problem statement, research gaps, aims, and questions which are revised and refined after the literature review in Chapter 2. Finally, the research approach, the work's contributions, and the overall dissertation structure are presented.

This doctoral project started on 1 October 2020 in the scope of the *Anthropolis Chair* led by Jakob Puchinger (2015-2022) and Flore Vallet (since 2022) and jointly operated by IRT SystemX and CentraleSupélec, Université Paris-Saclay. Four industry partners – EDF, ENGIE, Groupe Renault, and Nokia Bell Labs – from energy, mobility, and technology sectors, and CPS, the public inter-council partnership of Paris-Saclay, are part of the project consortium. The Anthropolis Chair works towards *people-centred and sustainable urban mobility* around the themes of infrastructure simulation, urban futures, and servitisation of mobility. Within the Chair, the doctoral project is linked to the task *futures of urban life and mobility*. People-centred is a term recurring throughout which is further defined later. Foremost, it refers to the central consideration of people, in this case those living, working, or otherwise populating urban areas. We call them *urbanites*.

On the academic side, the doctoral project is registered at the Doctoral School INTERFACES in the discipline of *Complex System Engineering* and conducted at the *Industrial Engineering Laboratory* (LGI, FR: Laboratoire Génie Industriel). Within the LGI, it is attached to the *Design Engineering* team as well as the transversal *Mobility Systems* theme. Furthermore, the doctoral project is conducted at the state co-financed Technological Research Centre IRT SystemX. IRT's mission is to act as an accelerator for the digital transformation of industry, services, and territories, in line with the vision France 2030. IRT's projects are conducted in close collaboration with the public and private sector, aim to address societal challenges, and integrate innovative technological solutions and methods throughout the process. Aside from the French context, a research visit of two months in Egypt and subsequent collaboration enabled adding the second case study of Cairo. The author stayed as a Visiting Scholar¹ at the *American University in Cairo*, hosted by Prof Dr Nabil Mohareb and Dr Sherif Goubran from the Architecture Department at the School for Sciences and Engineering, as well as a Research Fellow in the Data Team of *Transport for Cairo*.

Diverse lenses on urban mobility origin from each of these institutions, as well as the backgrounds of the doctoral candidate² in urban development and the members of the supervisory team. These will reappear throughout this dissertation. Nevertheless, the research is rooted in the field of design science, in particular regarding *design of complex systems*, referring to the methodical design and adaptation of new and existing products, services, and systems, with a particular focus on problem-oriented, result-based approaches and design process improvements. The theoretical foundations combine concepts of *design science*, *complex system theory*, *futures studies*, and to application-specific *mobility and urban studies theories*. The multi-disciplinary context results in a set of acronyms, abbreviations, and domain-specific terms, in some cases with contested meanings across languages or disciplines. A list

¹ As part of the Scholars without Stipend (SwS) programme of AUC.

² Appendix AP.4 contains the author's CV and a short overview of activities conducted during the doctoral project.

of acronyms and abbreviations preceded this chapter, while a complementary glossary can be found in Appendix AP.2.

1.1 Motivation and research aim

The motivation for this work originates from three levels. My personal objective builds on a search for ways to deal with uncertainties in complex urban environments and find adaptive ways which arose when working in Lilongwe and experiencing systemic challenges and fast-paced urbanisation for which traditional urban planning and design methods proved inadequate. The fascination evolved into a bachelor's thesis in 2015 with early exposures to uncertainty, wicked problems, and adaptive planning and design methods. Despite continuously accompanying studies and work thereafter, many questions remained unanswered. When first reading the PhD topic in summer 2020, I realised the opportunity to delve deeper into urban uncertainty and joined the Anthropolis Chair³.

When arriving in France, the Chair just started its second cycle. In the first, the work centred on advancing mobility simulations and developed user-centred design support systems. Along this work, different futures' works started, the key one on the co-creative development of future personas to better prepare for the needs and practices of tomorrow. This work led to the integration of a dedicated task and doctoral project into the second edition of the Chair. The ambition was to advance the structured exploration of futures in the design process of urban mobility systems (UMS), as well as identifying potentials of cross-pollinating simulations and foresight methods.

The third level of motivation emerges from the pressing socio-environmental challenges of present and future. The United Nations (UN) Sustainable Development Goals (SDGs) dedicated SDG11 to Sustainable Cities, with the sub-goal 11.2 calling for sustainable and inclusive mobility by 2030 (UN, 2015). These ambitions are further detailed in the New Urban Agenda (NUA) aiming to localise the SDGs in urban contexts (UN-Habitat, 2016), countless urban and territorial objectives and directives on EU-level, as well as two dedicated chapters in the last assessment report (AR6) of the IPCC (International Panel on Climate Change): AR6 Working Group (WG) II (Impacts, Adaptation and Vulnerability), Chapter 6 on 'Cities, Settlements and Key Infrastructure' (Dodman et al., 2022) and AR6 WG III (Mitigation), Chapter 8 on 'Urban systems and other settlements' (Lwasa et al., 2022). It is expected that the upcoming AR7 will focus even more on urban areas as arenas for transformation, while the according constituency of Local Governments and Municipal Authorities (LGMA) gains – even if slowly – a stronger voice at the global climate conference COP⁴. In a report on the occasion of the 75th anniversary of the UN, a perspective for the future was drawn, including five megatrends:

1. *'Climate change,*
2. *Demographic shifts, particularly population ageing,*
3. *Urbanization [sic],*
4. *The emergence of digital technologies, and*

³ www.chaire-anthropolis.fr [accessed 1 September 2023]

⁴ Conference of Parties (COP), annual climate conference to advance on mitigation, adaptation, and loss and damage, the global stock take, among others, within the United Nations Framework Convention on Climate Change (UNFCCC)

5. *Inequalities*' (UN, 2020)

Each of these five topics are strongly linked to urban mobility and the futures thereof. This doctoral project hence aims to contribute to *sustainable urban development* and the design of *urban mobility systems*. An urban mobility system (UMS) refers to a multiscale and multi-disciplinary complex adaptive system that defines personal mobility taking place in the primarily continuous daily territories of the residents/users of an urban (or metropolitan) area.⁵ A central assumption underlying the research is that the strategic use of futures can positively affect the process of designing sustainable and people-centred UMS.

We focus on *urban areas* as the most polluting and resource-consuming areas, with the urban transportation and mobility sector being one of the key contributors at about 8% globally (Creutzig, 2016), aside from negative externalities such as local air and noise pollution or accidents. At the same time, many solutions and approaches exist, yet are still lagging significantly behind the needed progress to achieve global climate objectives. Aside the environmental dimension, the current situation of urban mobility has widespread negative impacts on urbanites, mostly linked to socio-spatial injustices. These span the spatial exclusion from affordable and sustainable mobility modes, restricted accessibility to the job market and basic urban services such as healthcare and public services, and unequally distributed financial and commuting time losses.

On the methodological side, *UMS design* is impacted by long processes due to lifespans of infrastructure and even longer spatial impacts, as well as long idea-to-market periods for complex mobility solutions. Solutions in this context refer to mobility services, products, as well as plans and policies. This longevity is matched by an increasingly fast-changing context of technological changes and volatility to events such as the Covid-19 pandemic, resulting in high levels of future uncertainty.

This work's motivation is contributing to the design processes of *urban mobility solutions*, referring to all types of products (e.g., e-scooters), services (e.g., ride-hailing) or policy (e.g., financial subsidy for purchasing e-bikes) interventions that address urban mobility challenges, and better preparing them for a sustainable and people-centred future by systematically integrating *future uncertainties*. These uncertainties refer to social, environmental, or technological future developments for which it is impossible to know today, how they will develop. For example, how many people will want to have a personal car? What will be the oil and electricity price in 2030? Or what will be the average emission level of the vehicle fleet in 20 years? The envisaged audience of the developed approaches and tools are key stakeholders who define local UMS (Figure 1). This includes the local public and private sector, as well as the civil society. The application cases used in this work are primarily targeting the public sector. The next section outlines the research background with a focus on the larger conceptual elements of *urban systems, wicked problems, and uncertainties*.

⁵ This definition is an early version of the working definition of the author. Its origin will be detailed later but the shortened inclusion here shall aid a common understanding of used terminology.

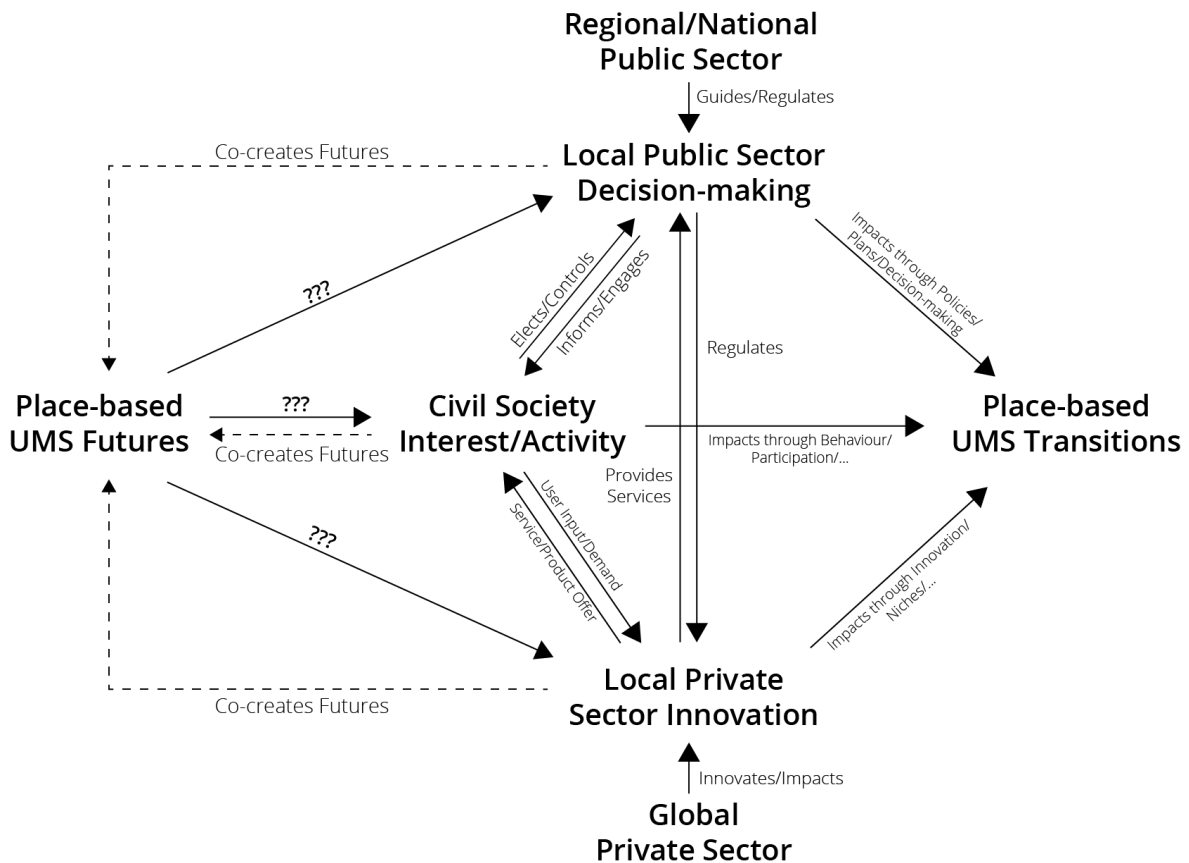


Figure 1: Interaction of place-based Urban Mobility System (UMS) futures, local and global stakeholders, and UMS transitions (CC BY 4.0)

1.2 Research background

Consequently, the initial challenge for this doctoral project is how future urban mobility can be designed and planned to render it more sustainable and people-centred. This section presents an initial scoping literature review on the three key areas of interest: 1) Urban areas and urban mobility as complex systems, 2) The ‘wickedness’ of the associated problems and challenges, and 3) The uncertainty and non-deterministic future.

1.2.1 Urban areas and urban mobility as complex systems

Continuously urbanised and populated areas – henceforward referred to as cities regardless of administrative boundaries – are home to most of the population today, with a continuing trend to up to 70% urbanisation by 2050. In many ways, cities can be seen as a representation of society with its complexity, multiple dimensions, and positive and negative feedback loops and attributes (Bacon, 1985; Sennet, 1970; Sassen, 2013). While bringing about economic growth, innovation, and many other positive effects, cities are also home to widespread inequalities, poverty, pollution, resource overconsumption, among others. When we attempt to plan or change components of the city, such as the mobility system, we quickly realise its complexity and interconnections.

Jane Jacobs (1961), leading advocate for people-centred cities, and Jay W. Forrester (1969) were early proponents of conceptualising cities as complex systems. Jacobs states that cities ‘present “situations in which a half-dozen or even several dozen quantities are all varying simultaneously and in subtly interconnected ways.”’ Cities,

again like the life sciences, do not exhibit *one* problem in organized [sic] complexity, which if understood explains all' (Jacobs, 1961, p. 433, citing Weaver, 1948). She further points out that 'theorists of conventional modern city planning have consistently mistaken cities as problems of simplicity and of disorganized [sic] complexity, and have tried to analyze [sic] and treat them thus.' (Jacobs, 1961, p. 435; cf. Goodspeed, 2020). While some progress has been made since and the system character has found broader application, the scale and scope of problems within the urban realm grew as well.

The urgency of systemic thinking towards more sustainable and inclusive design and planning is highlighted across scales and fields, for example, anchored in the aforementioned UN SDGs (UN, 2015), the Paris Agreement (COP21, 2015), estimations for the irreversible tipping point of the global climate (IPCC, 2014; IPCC, 2021), among many others. Further, concerns of direct and indirect societal impacts of products and services arise (cf. Rifkin, 2011). In the mobility context, greenhouse gas (GHG) emissions of the transport sector alone are with 22% at the second place, or 8% just for urban transport (Creutzig, 2016), while 1.3m people are killed on roadways annually (Climate Watch, 2020; CDC 2020). Further, it competes for sparse land resources in an urbanising world. In Paris, for example, road infrastructure takes up 27% of its valuable space, 57% of which for cars (Héran and Ravalet, 2008).

Mobility not only requires lots of *space* but also uses other *scarce resources, including oil and rare materials* (Metabolic, 2019), and creates negative externalities for the society through congestion-induced loss of economic productivity, estimated at up to \$14bn per annum in Paris alone (Cebr, 2014). The impacts of a century of fuel-based vehicle transportation are significant for societies today (e.g., through air pollution and increasing and aggravating disasters) and will be even more so in the future, requiring reduction of transport-related emissions and the transformation of UMSs globally (COP21, 2015; UN, 2015; UN-Habitat, 2016). When we look at future population growth primarily concentrated in the Global South in current low-income countries, combined with an exponential increase of travel distance, share of income spent on vehicles and transport, and tons of CO₂ emitted per person per year that accompanies countries' development (Rosling et al., 2019, p. 98), and an ongoing significant export of outdated concepts, ideals, and technologies from 'developed' to 'developing' countries, the perspective becomes even darker. Thus, the active transformation of UMSs is paramount to allow for sustainability transitions. This comes with various challenges and requires an understanding of what the UMS is, what its components, functions, and stakeholders are, and how it relates to other urban sub-systems, such as energy, land use, or economic systems. This topic is identified as the first area of interest this project aims to contribute to.

1.2.2 Wicked, or super wicked problems

Taking UMSs in the context of complexity and the long list of negative externalities, we can have a closer look at the possible transitions. A transition can be described as a process from one state at one point in time to another. To design or manage such transition, one must define what state we are aiming for. However, in the context of urban planning or UMS design, this is hardly the case. While we might define zero Greenhouse Gas (GHG) emissions as the goal, there is no agreement if this shall be achieved through smaller or bigger cities, densified or sprawling areas, 15-minute cities or metropolitan regions, or no personal cars or instead only electric cars, to just name a few frequent disputes. Rittel and Webber (1973) named these problems

wicked problems due to their complexity and challenges, defined by ten characteristics. Three of these are that they do not have a *stopping rule*. In other words, these problems lack an inherent logic that signals when they are solved, there is ‘no ultimate way to test the solution to a wicked problem’ and there is no end to the number of solutions or approaches to a wicked problem (Rittel and Webber, 1973, pp. 161-167). Levin et al. (2012) go one step further and define *super wicked problems* as those where ‘time is running out; those who cause the problem also seek to provide a solution; the central authority needed to address it is weak or non-existent; and, partly as a result, policy responses discount the future irrationally.’ (p. 123)

There are various possible responses to this dilemma. In the urban contexts, a common concept states that we are rather a planning society than a planners’ society (Dewey, 1922), meaning that ‘the purpose of planning is not to realize [sic] or control a specific future but rather to make more intelligent, progressive solutions today, especially those that have likely long-term consequences’ (Goodspeed, 2020, p. 13). In transition design or management concepts, oftentimes the direction or trend is prioritised over the defined final state. Another cross-discipline approach is that of participation or, most specifically, co-creation. The co-creation with various actors, sometimes even representing future societies (cf. Uwasu et al., 2020; Nakagawa and Saijo, 2021), is claimed to achieve a decentralised decision-power, spread knowledge, possibly sometimes foremost distributed responsibility, but in principal that decisions today are made not by powerful individuals but by those making up the society and being directly or indirectly affected by it. The integration of the co-creation of urban futures and mobility solutions, referring to the ‘active flow of information and ideas which allows for participation, engagement, and empowerment in [...] tackling systemic change’ (Agusti et al., 2014, p. 3, cf. Arnstein, 1969) is, therefore, understood as important puzzle piece for wicked problems due to its complex multi-stakeholder environment.

Lastly, as we are discussing UMSs in specific geographical contexts and assume the individuality of each combination of complex system(s) and its wicked problems, we build on the concept of *place-basedness*, referring to ‘characteristics and meaning of places as a fundamental starting point for planning and development’ (Staffans et al., 2010). This is fundamental for the understanding of UMSs and their transitions as such systems can be conceptualised as multiscale, nested systems with location-specific characteristics, stakeholders, problems, as well as solutions (Gall et al., 2021a).

To summarise, the challenges related to urban mobility (e.g., pollution, accessibility, resource-use) require the transformation of complex UMSs, which, however, do not have a singular defined solution but instead a complex network of actors with possibly opposing interests. In this context, design and planning decisions about varying potential solutions must be taken in a context of incomplete information (cf. bounded rationality, Simon, 1983). Incorporating a ‘the path is the goal’ mentality which focuses on the *constant and iterative transformation* more than on the outcome, *co-creative practices*, and a *place-based contextualisation* of systems and problems, appears to be a suitable mix of promising responses to wicked problems.

1.2.3 Future uncertainties and multiple, possible futures

Additional to complexity and wickedness, we are operating in a *field of uncertainty*. Multiple future trends can significantly impact the UMS and its trajectory. These range from population dynamics, resource scarcity, geo-political instability, as increasing at the time of writing, to new innovations. Consequently, we are situated in a context

where there are multiple possible future outcomes, depending on the trends and developments. Further, as highlighted in the section on wicked solutions, there is not one individual outcome that can be established as objective. Taking a non-deterministic stance, we can assume a (infinite) multiplicity of possible future states from which some are ‘bad’ and some are ‘good’, ‘unsustainable’ or ‘sustainable’, depending on how we define each of these terms. Therefore, a range of *multiple, possible solutions* could manifest.

The discipline of design describes the process ‘to devise courses of action aimed at changing existing situations into preferred ones’ (Simon, 1996). The process of moving from the current system state to one or several states in the future can be supported by different concepts. General *futures thinking* conceptualises the future as a possibility space with multiple (or infinite) possible trajectories (Dator, 2019; Inayatullah, 2013; Candy, 2010, Gall et al., 2021c). One or several of these possible futures can be selected as different, *possible, plausible, or preferred scenarios* or visions. Scenarios are defined as a set of distinct, plausible, and possible future alternatives, supported with a narrative (Spaniol and Rowland, 2018).

Most existing works on urban mobility transitions have been done with singular or limited numbers of *scenarios*, based on prediction models of, e.g., how much traffic demand there will be, or how much GHG emission can be saved. The former case leads to reinforcing the current state instead of fostering systemic changes while the latter fails to address multidimensional issues or propose a pathway to get there. It is argued that a more explorative, multi-faceted, and foresight-oriented approach on futures could address this more adequately as it proposes actions along the way (e.g., through backcasting (Dreborg, 1996; Inayatullah, 2013). Simultaneously, multiple futures can act as individual, preferred futures, visions as beacons to work towards, or as multiple preferred futures as a future scope of possibilities to ‘transcend’ towards (Inayatullah, 2013; cf. ITF, 2021).

From futures literature, we identified the extensive treatment of conceptual futures and scenario-thinking (Inayatullah, 2013; Candy, 2010; Dator, 2019; Fergnani and Jackson, 2019), its linked methods and tools (Spickermann et al., 2014; Johansen, 2018; Soria-Lara et al. 2021; Navarro-Ligero and Valenzuela-Montes, 2016; Molinero-Parejo et al. 2021; Uwasu et al., 2020), a variety of transition approaches, compilations of future trends and an urban mobility scenario compilation (Miskolczi et al., 2021). A frequently mentioned gap is the empirical assessment and validation of scenarios and their impact on design processes (Goodspeed, 2020; Fergnani and Chermack, 2020). Furthermore, mostly when situated in the public sector, there is often the mention of a lack of resources to perform scenario planning adequately, restricting its potential for more widespread application (Goodspeed, 2020).

1.3 Problem statement

The public and private actors, involved in the design of solutions for local UMS that shall address embedded challenges, need methods and tools to systematically integrate future uncertainty in design processes – a need expected to grow further in the future with ongoing complexification and higher uncertainties resulting from, e.g., the climate crises. We initially conceptualise this process as visualised in Figure 2. One phase focuses on *co-creating scenarios*, one on *transition design*, and one on *UMS solution design*.

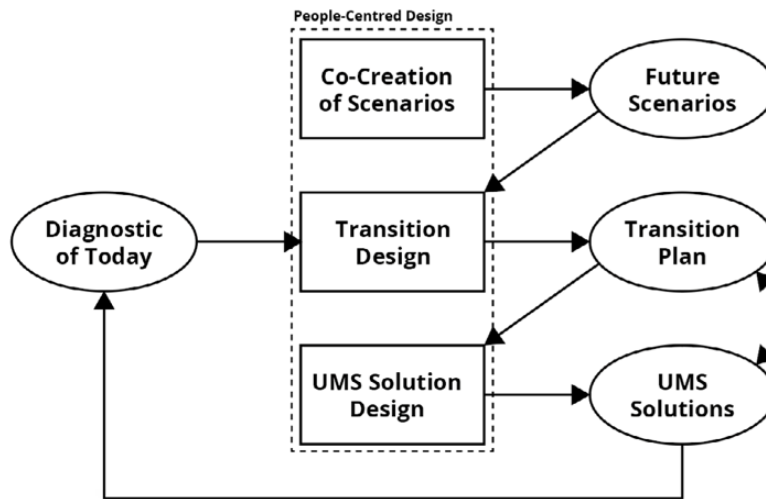


Figure 2: Different design processes and artefacts involved in design of urban mobility futures (CC BY 4.0)

The focus of this work is on supporting the last phase of *designing mobility solutions* in direct relation to the present situation. Within that focus, we target the following problems and their interactions:

1. High-stake socio-environmental challenges in urban mobility,
2. Systemic wicked problems defined by uncertainty and a lack of clear solutions,
3. Lack of localised, place-based approaches, and
4. Little research on using futures strategically in design processes for urban systems.

1.4 Initial research objectives and questions

In response to these challenges, we aim to establish a *design support framework* that can address some of these. The target audience includes actors of UMSs, such as local authorities and private companies, as well as researchers in the fields of design science, mobility, and urban studies. The most conceptually adequate approach appears to be the *use of scenarios* as they are on the one side integrating uncertainties, but also representing multiple possible solutions in a situation where we do not know what the goal might be. Consequently, the objective arises to *develop and test heuristic, scenario-based approaches that can reduce the complexity* and assist in the integration of UMS futures, their representation, assessment, and interaction with other methods (such as simulation) to enrich the design support framework for urban mobility solutions, as well as planning and policymaking.

From the research objectives, one guiding research question (RQ) is defined. This question is refined based on the literature review and identified gaps in the next chapter:

Initial RQ: How to integrate uncertainties in designing solutions for UMS?

1.5 Research approach

In this section, we briefly introduce the research approach while the detailed methodology is described in Chapter 3. The overall approach follows the concept of *grounded theory*, defined as ‘a way of generating new theory grounded in the field but also set in the context of existing theory’ (McGhee et al., 2008, p. 335; cf. Glaser and Strauss, 1967). This choice is motivated by the applied context and the objective to contribute practical new methods while also contributing to the theoretical discourse.

Within this framework, we make use of approaches from different disciplines. At the core is the Design Research Methodology (Blessing and Chakrabarti, 2009), supplemented with conceptual elements of design engineering, and methodological elements for the qualitative analysis from social sciences. The mixed-method approach combines desk-based research, qualitative case study research, and empirical design research elements. Finally, a set of quantitative analysis and simulation tools supplement application parts of the case studies.

To use this research approach in the context of UMSs, a clear definition of its system is crucial. Building on the earlier working definition of UMSs by the author as multiscale and multi-disciplinary complex adaptive system, it can be further understood as constituted of several sub-systems, spanning from the metropolitan to the local scale, and encompassing both social and technical elements. It constantly changes through internal and external dynamics yet retains a recognisable system state. The research approach uses this initial definition and expands, tests, and substantiates it via interviews, workshops, and empirical data. This definition is formalised in Chapter 4.1.

The system definition permits tackling the timely, wicked, multiscale and multi-stakeholder challenge of providing sustainable mobility solutions, especially in peripheral areas in metropolitan regions with a stark mismatch of car-dependant hinterlands and car-restrictive centres.

Identified local projects and stakeholders allow conducting interviews and participatory workshops to compile relevant information, resulting in the validation of initial assumptions, models, and relationships through workshops and interviews. Finally, the experimentation of produced models and methods is achieved through in a multi-stakeholder context via a number of workshops, extended into two application case studies, first in Paris and, thereafter, in Cairo. In summary, a literature review and desk research on systems, transitions, and futures (Chapter 2) is followed by interviews and workshops, leading to a set of initial models and methods (Chapter 4) which are tested, refined, and validated across two geographical contexts (Chapter 5). The detailed methods are described in Chapter 3.

1.6 Scientific contributions and methodological advances

This research aims to contribute and support design processes of UMSs and solutions across disciplines. The resulting contributions include the following methodological framework and tools:

1. An *Urban Mobility System (UMS)* model, including its components and dynamics.
2. A refined *futures representation* to enable prospective co-creation.
3. An *UMS design framework* with an ordered approach to adapt UMS to different future scenarios.
4. Three contributions to an UMS design toolbox, namely, a *scenario localisation method* and a *future synthetic populations' method* to vary future populations according to existing scenarios and integrate them into agent-based mobility simulations, as well as an *urban impact assessment tool* to accompany this process.

All elements are developed in the context of Paris, and, except for the interactive tool, replicated and validated in the context of Cairo.

1.7 Dissertation structure

These contributions are developed in several steps which constitute the foci of the subsequent chapters. The dissertation is structured in six chapters including this introduction, visualised in Figure 3.

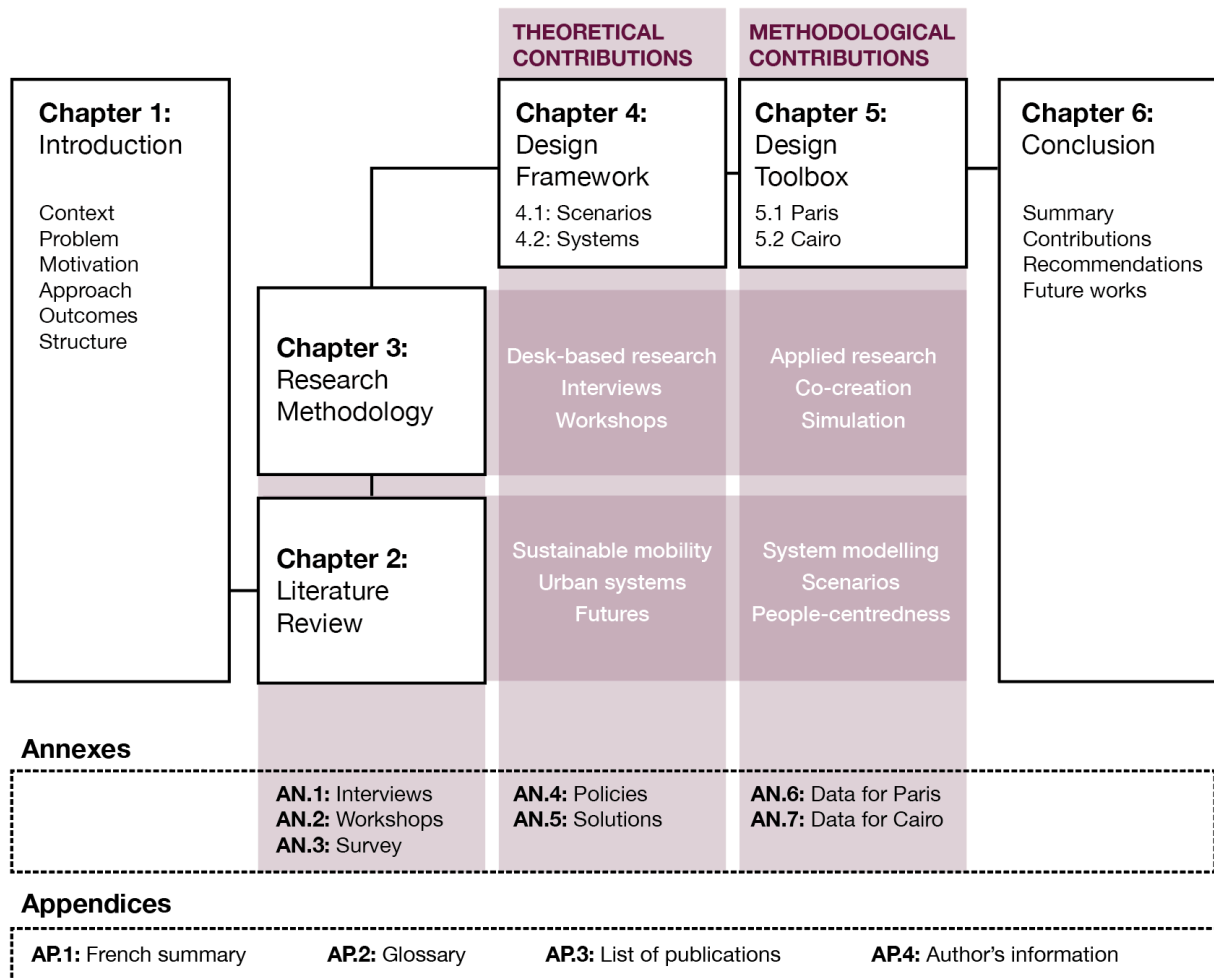


Figure 3: Dissertation structure

Chapter 2 provides a literature review of three core elements: 1) Sustainable urban mobility, 2) Design for uncertain futures, and 3) Design for future urbanites. It concludes in a set of identified research gaps and questions.

Chapter 3 describes the overall research approach and methodology used in the subsequent sections.

Chapter 4 introduces the developed design framework for future urban systems. The first part focuses on scenarios as method to work strategically with futures. The second part focuses on modelling urban systems, followed by the framework that combines future scenarios and the urban system model.

Chapter 5 applies the framework to the case of Paris and presents the applied research process resulting in methods to localise scenarios, create a set of present and future urbanite models, and use them for a collaborative tool and agent-based simulations. The second part focuses on validation by testing the developed process in Cairo, replicating the scenario localisation, the creation of intermediary design objects, and agent-based simulations. The chapter concludes with a discussion of methodological contributions.

Chapter 6 provides an overall summary, overview, and discussion of this work's contributions, a resulting set of recommendations for theory and practice, and an outlook on potential future works.

The **Annexes** include a range of complementary materials such as workshop and data collection descriptions, created databases, or additional information for the two case studies.

The **Appendices** contain the French summary, a glossary, a list of publications, and the author's information.

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The future cannot be predicted because *the* future doesn't exist.

Jim Dator, A Noticer in Time

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2 LITERATURE REVIEW: DESIGNING FUTURE URBAN SYSTEMS

Building on the scoping literature review, the introduced problem statement, as well as the initial research question, this chapter provides a more in-depth overview of existing literature and concepts on the core fields. The first sub-chapter focuses on sustainable mobility and its role and context within urban systems. Some examples are taken from the French context, but the detailed case study introductions follow in sub-chapters 5.1.1 (Paris) and 5.2.1 (Cairo). The second part delves deeper into futures studies with a focus on scenario-based approaches. Finally, we review a number of concepts and methods from the design studies context. Each of the sections results in a list of selected key research gaps we identified and aim to contribute to with this work. The fourth and last sub-chapter summarises the research gaps and presents the refined research questions. This chapter constitutes the theoretical and conceptual foundation for Chapters 4 and 5, and indirectly Chapter 6 (Figure 4).

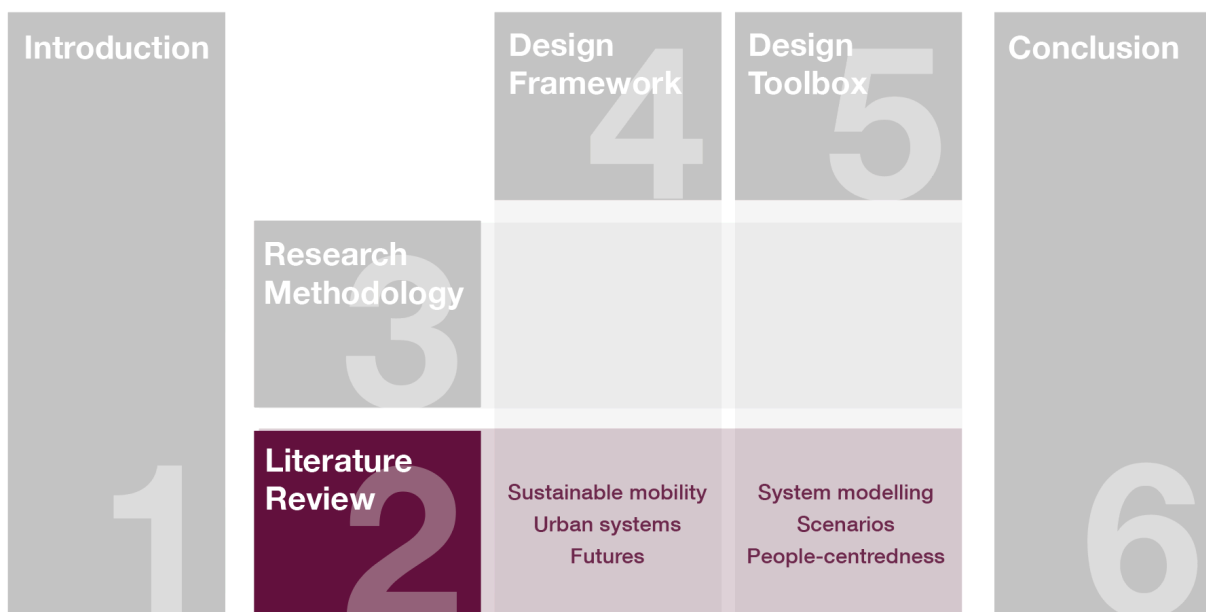


Figure 4: Chapter 2, Literature Review, in the overall dissertation structure

2.1 Challenges of sustainable urban mobility

One of the overall objectives of this work is the transition towards reduced negative impacts of the urban mobility sector on the global climate, environment, and people. As the connection between mobility and emissions is not simply linear but instead complex and multi-layered, a systemic view is crucial. A variety of dimensions have an influence on the overall impacts of mobility, including demographic changes, the economy, lifestyles, transport modes, technologies, policies, urban development, energy, resources, among others. We discuss some of the most important ones which act as foundation of the subsequent chapters. The objective is the introduction of the notion of *sustainable urban mobility*, including its components of sustainable urban development, sustainability, the urban context, and mobility as specific field of application.

2.1.1 Urbanisation

Ongoing urbanisation led to urban mobility being a topic of interest in the first place. While the world urbanised for centuries, combined with the overall population growth

and peaking urbanisation growth rates in the past century, urban areas are today home to 55% of the global population. By 2050 an additional 2.4 billion urban dwellers are expected. At the same time, more megacities of over 10 million inhabitants arise, most rapidly growing in the Global South and creating various challenges, ranging from inequality to self-planned settlements with lacking services and amenities. (L'Institut Paris Region, 2019) Already today, urban areas are in many cases more powerful compared to their respective countries or others, making urban areas the power epicentres of today and most likely even more so in the future.

Three considerations are important to be pointed out. First, the challenges, its responses, and overall developments of urban mobility in metropolitan and megapolitan regions will define the lives of the majority of the global population, at least in the near future. Second, many urban cores are already highly densified with developable land becoming a scarce resource. This leads to urbanisation being accompanied in many cases by urban sprawl, informal land use or self-planned growth, environmental degradation, or disconnected housing and new town developments; each of them coming with a particular set of challenges for urban mobility to address or react to. Lastly, the majority of urban growth will not happen in the already highly urbanised and developed regions of the world, but continue in Asia and South America, as well as accelerating further on the African continent. This extreme localisation results from comparatively low urbanisation levels (except in South America) and high urbanisation rates, continuous natural as well as rural-urban migration-inflicted population growth, urban economic development, and transition from leading rural to industrial and service-oriented economies (Hoornweg and Pope, 2017, UN, 2018).

The focus on *urban* mobility futures is thus justified by urbanisation itself, challenged by resulting spatial and societal developments, while requiring a response which takes globally divergent patterns into consideration.

2.1.2 Glocalisation

A second concept, directly linked to urbanisation, is glocalisation. The term is a combination of the term globalisation, referring to the increasingly global markets, value chains, societies, networks, and interconnectivities, as well as the seemingly opposing notion of localisation. It describes a dualistic trend of both *increasing global and local networks across domains*. Globalisation has shaped today's world, primarily resulting from developments of the last two centuries, enabled by new modes of transport for people and goods and advances in telecommunications, among others.

At the same time, trends towards localisation arise. Jeremy Rifkin's perspective on the Fourth Industrialisation Revolution focuses for example on the trends towards decentralisation of energy-production, the resulting uprooting of traditional centralistic power distributions, and the arising opportunity of more localised social networks, as well as pro-consumption patterns (Rifkin, 2011).

Further, increasing concerns arise from the negative long-term impacts of anonymity and disconnection to the immediate social and environmental surroundings in urban areas, accelerated and enabled through increasing digitalisation and widespread uprooting from traditional community networks. Rifkin (2011) provides the example of disconnection to the natural habitat when growing up in urban areas and its proven detrimental impacts on humans' capacity for empathy among others. A multitude of studies sets out to quantify the impacts of urbanisation and urban life on mental health. While a negative impact on depression and stress levels is agreed on, the

search for impacting factors goes in different directions. However, a relationship between mental health and the level of social capital, resident continuity, and provision of places for interaction and exchange, seems to prevail.

Looking back at the evolution of species, applying the concept of Mutual Aid introduced by Kropotkin (1902) as a supplementary, rather contrary concept to Darwin's survival of the fittest, can add to the localisation discourse. Kropotkin studied the evolution of various types of animals and human tribes and found patterns of community behaviours such as mutual aid as a significant contributor to the evolution and prosperity of the group. Starting in the very early history, he traces developments thereof surviving as important factors until the urban age, when trade communities or neighbourhoods continued to support each other and contributed to their community. The widespread urbanisation, migration, relocation, and expanding reach through mobility and telecommunications, as well as accompanying consequences such as geographically distant networks to family and friends or local anonymity, have resulted in continuously deteriorating local community structures in urban areas (most notably, Appleyard, 1982).

Today, many projects, initiatives, and trends can be found which are intending to reverse this trend, with results thereof constituting an often-found reference in existing urban future scenarios. These include, among others, human-centric urbanism (building on Jane Jacob's and Jan Gehl's work), placemaking, the 15-minute-city, child-friendly or inclusive urbanism, know-your-neighbour initiatives, or platforms for support or local trading networks. Despite of a lack of a systemic understanding and diverse responses, the dual role of global and local networks has defined the growth of urban societies and will continue to do so, resulting in varying drivers and constraints for urban mobility futures.

2.1.3 Sustainable urban development

Adding a normative layer to urbanisation and the parallel process of glocalisation, *sustainable urban development* constitutes the foundation for many of today's policies, projects, and studies in the field of urban development, as well as urban mobility. The term 'sustainability' origins from the field of forestry where sustainable was coined as planting and harvesting as many as possible but no more trees to sustain the business operations. In 1987, the World Commission for Economic Development (WCED) included sustainable development in their report 'Our Common Future' and it has been used across disciplines since. The original and often quoted definition given in the report states that 'Sustainable development [...] meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED, 1987), providing the direct link to the future integration.

Initially focusing on the environmental dimension, the notions of social and economic sustainability were added over time, highlighting the applicability of the concepts across sectors, as well as the interrelation between dimensions of sustainability, with sustainable development being the combined result of all three, and its governance being the common denominator to do so (often enriched with the Quadruple Helix).

With varying reports, approaches, and applications to follow, the establishment of 17 SDGs in 2015 and their respective sub-objectives, has defined the sustainable development discourse since. Here, SDG 11 Sustainable Cities and Communities and SDG 13 Climate Action are leading, while the majority of the other SDGs are directly related as well. Sub-goal 11.2 calls to 'by 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably

by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, persons with disabilities and older persons' (UN, 2015).

Furthermore, the Paris Agreement (COP21, 2015) signed in the same year, became a leading and binding global agreement to implement actions to address climate change in government policies. In particular relevant for the context of urban mobility are the vows to keep 'the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels', by regularly measuring the levels and strategically mitigating GHG emissions while fostering sustainable development.

In the context of urban areas, various policies and tools followed to define sustainable urban development. This includes for example the New Urban Agenda (NUA) which has been adopted as response to SDG 11 at the UN Conference on Housing and Sustainable Urban Development (Habitat III) in Ecuador in 2016 (UN-Habitat, 2016). The NUA calls for the 'city for all' and 'right to the city', with equal access and opportunity, in particular 'equal access for all to public goods and quality services in areas such as food security and nutrition, health, education, infrastructure, mobility and transportation, energy, air quality and livelihoods.' (UN-Habitat, 2016). Further, the NUA calls for the promotion of 'age- and gender-responsive planning and investment for sustainable, safe and accessible urban mobility for all and resource-efficient transport systems for passengers and freight, effectively linking people, places, goods, services and economic opportunities' (UN-Habitat, 2016). These goals have been localised across the world since, for example through National Urban Policies, and more recently the movement towards National Urban Agendas within the European Union.

On the climate side, various policies and plans target building resilience against the adverse consequences of climate crises. Most of these are partially caused by the field of mobility (for example, through global GHG emission, local air pollution, or sealing of permeable ground). Further, many responses to climate risks in cities are directly linked to mobility solutions, across the fields of mitigation, adaptation, and resilience. *Adaptation* is the umbrella term for adapting to climate change. It builds on the adaptive capacity of a system, defined as the 'ability of a system or individual to adapt to climate change' (Cardona et al., 2012, p. 67) and can be divided in the capacity to anticipate risk, to respond, to recover and change and, therefore, is often compared or even equated with resilience (Cardona et al., 2012). As adaptive capacity depends heavily on the environment and system which is looked at, constituting or influencing elements are generally resources, knowledge, and institutions' characteristics (Adger 2006; Adger 2007; GIZ 2014). *Mitigation*, on the other hand, is often discussed independently from adaptation due to its preventive instead of responsive character. It can be defined as the combined action to reduce GHG emissions and other outputs which cause, accelerate or otherwise negatively affect the climate crisis.

Additional to the environmental dimension of sustainability, also social and economic elements are part of most sustainability definitions. The social dimension focuses primarily on ensuring basic capabilities, equal access to opportunity, and poverty alleviation. In the context of sustainable urban development, the perspectives change significantly in the context. Social issues in Helsinki differ broadly from those in Paris, Beijing, Casablanca, or Cairo. Nevertheless, a few concepts are noteworthy.

Some recent concepts include child-friendly design and designing Cities on Eye Level (for adults and/or for children). The related concept of 8-80 builds on the idea that a city designed for 8- and 80-year-olds is suitable for everyone, addressing issues of inclusivity and accessibility. Other concepts can be grouped under placemaking, which is a participatory process to convert spaces into places, with the first referring to a physicality, and latter referring to an associated, co-constructed notion of meaning. Implications thereof can range from increasing local social interaction to emancipation and empowerment, as discussed in Lefebvre (1991), Foucault (in Grbin, 2015), Appleyard (1982) or Soja (2009). Lastly, a variety of social concepts centre around measuring or enabling accessible cities, both under a city-wide and local perspective, as well as targeted public or social housing policies.

Finally, sustainability also contains an economic dimension. As urban areas are in many cases the engines of the global economy, the economic dimension is as complex as the city itself. Most importantly, if sustainable urban development allows for or is accompanied by economic prosperity, its implementation and scaling up is more likely, hence economically sustainable. Furthermore, social accessibility as discussed in the previous section, is linked to affordability and, therefore, cost of different mobility modes and housing in more-or-less accessible locations.

2.1.4 Urban mobility

Building on the above sections, we limit our focus on urban mobility, understood generally as *daily mobility of people within an urban area*. This section delineates what is referred to with urban mobility more in detail while introducing some key concepts and developments which are impacting it.

Mobility is seen as the actual geographical change of location (mobility) or the capability thereof (motility) by humans, regardless of the mode and mean. It includes the notion of the intention of moving from one point to another, as well as that of the movement for the purpose of the movement itself. (Kaufmann, 2002, 2011; Urry, 2002) It includes mobility of various types, including individual and collective; public, private, and shared; motorised and non-motorised; commute and leisure trips, change-of-location or motion-based movements. On the other hand, in this thesis it clearly excludes any movements of goods of any kind (city logistics, freight), long-term movements such as migration or nomadism, as well as social mobility. The latter is however considered to a certain degree due to it being possibly altered by urban mobility.

Urban refers to the mobility in an urban area, defined as an area with a certain population density (varying by context) and the existence of societal, cultural, economic, administrative functions and coherent and continuous structures. The contexts of Paris and Cairo are (urban) metropolitan mobility areas. This refers to a connected and continuous urban area which jointly constitutes a functional metropolitan area, determined foremost by the daily territories of its permanent and temporary residents (cf. French concept of *bassin de mobilité*). It must be anticipated that the area will change over time and has different extents today compared to those of studied points in time of future scenarios.

Hence, *Urban Mobility* is the actual or intended human movement within or from and to an urban area. Banister (2008) describes the stakes of sustainable urban mobility as more than just the movement of people and goods within cities, but also the interplay between transportation systems, land use patterns, environmental considerations, and social equity. Consequently, *sustainable urban mobility* aims to

balance between meeting the diverse mobility needs of urban populations while minimising negative environmental impacts and fostering inclusive and equitable access to transportation. (Banister, 2008)

To operationalise this, various assessment frameworks have been developed. The leading ones are the triple-bottom line of sustainability with the environmental, social, and economic dimension, or its stylised private-sector equivalent People-Planet-Profit. In the mobility sector, two recent compilations of indicators by Chatziioannou et al. (2023) and Xenou et al. (2021) are noteworthy, as well as a targeted assessment framework for Shared Automated Electric Vehicles (SAEV; Horschutz-Nemoto et al., 2021).

In general, mobility and sustainable urban development are highly intertwined. Cities arose as marketplaces and nodes in an interconnected network, with the movements in between them and within defining their development and growth. The increasing pace and reach of means of mobility allowed for the spatial expansion of cities, as well as the globalisation of their markets and residents' network. Further, spaces and streets as physical manifestations of mobility paths have defined the layouts and spatial patterns of cities. Until today, highways, railways, or major roads are cities' arteries, as well as barriers.

Mobility is one of the determining factors for the access to housing, amenities, services, or transport itself. For that, a variety of types of mobility exists and have significantly expanded in diversity over the recent year, including shared, collective, active/soft mobility, or autonomous mobility. The sub-concepts of *Urban Form*, *Hypermobility*, *Transit-Oriented Development and Intermodality*, *Digitalisation*, and *Changing ways* of life are described below to zoom in on some of the leading present and anticipated future developments relevant for this project.

Urban Form

A key determining element for urban mobility is urban form; the built embodiment of the urban society, spanning macro-, meso- and microscale (city, settlement/neighbourhood, building). Urban form is constituted of different layers, including the street networks, built environment, and land use/division (Pont and Haupt, 2009; Oliveira, 2016; Hillier, 2009). The urban level (macro scale) includes the demarcation of the urban agglomeration and is necessary to understand larger interrelations, e.g., the accessibility to the economic centres or differences between core and peripheral areas. The community level (including both meso- and microscale) considers the built environment and includes, amongst others, building density, space allocations, proximities, or the density of street intersections. Various interrelations between urban form and sustainability have been studied, stating, for example, that smaller, denser, and more interconnected cities are more sustainable (cf. Adolphe, 2001; Oliveira et al., 2014; Jabareen, 2006; Fragkias et al., 2013; Dave, 2010; Louf, 2014). An often-quoted reference for the large-scale relationship between density and transport-related energy consumptions is the Newman and Kenworthy hyperbola which shows a strong co-variance, as well as a pattern of urban areas from different global regions. It showcases a clear relation between higher density resulting in lower emissions per capita (Lefèvre and Mainguy, 2009; Newman and Kenworthy, 1989).

In the mobility-specific context, Le Néchet (2012) points out that density, sprawl, and polycentricity can 'enrich the study of mobility patterns' and that the transport-related per capita energy consumption is partially related to elements of urban form. He found that 'energy consumption is larger in a rich, motorized [sic], sprawled, diffused and

polycentric city' while the contrary compact city seems to have a higher fatality rate. Without aiming to define the 'right' level of density or spatial characteristics, Le Néchet (2012) points out the importance to study the complex relationship of urban form and mobility and consider it for imagining and planning future urban mobility.

Urban form is also intertwined with mobility on a smaller scale. Two aspects are important. First, the density within a certain area defines the number of inhabitants and the related services or functions. Various decisions are made based on the density of an area, both from the public and private side. For example, the number, location, and size of healthcare services, schools, supermarkets or food franchises is oftentimes based on the population in the catchment area thereof. Furthermore, higher density increases the number of places which can be reached within a certain timeframe. However, monofunctional density (e.g., a business centre or large-scale housing project) comes with various challenges. Hence, high density must be combined with a multifunctional mixed-use neighbourhood to fulfil its primary functions. This relationship has been integral to most historic cities and was re-introduced under various names over the last decades. Most recently, the term of the 15-Minute City has gained global attention due to its re-conceptualisation and advocating by Sorbonne Professor Carlos Moreno, and its integration into the re-election campaign of Paris' Mayor Anne Hidalgo (Allam et al., 2022).

Many more determinants of urban form and mobility have been studied whose inclusion is outside the scope of this work. These include, for example, the optimal block size, number of network nodes, complexity or organicity of urban environs, active facades, social security due to mixed-use, as well as lightening and air movements, all with impacts on, for example, a higher likelihood of using, visiting, or passing through a space, hence, impacting mobility patterns.

Hypermobility

The concept of *hypermobility* describes the result of increasing speed, distances, access and frequency of mobility which followed the constantly evolving means of transport capabilities. This development is sometimes termed as out of scale or pace for humans, leading to a disconnection and growing disparity. Further, Khisty and Zeitler (2001) point out an imbalance which came along with this development, in particular that the expansion of motorised transport networks for higher speeds resulted in traffic jams which have significantly reduced mobility, accessibility and business productivity, increased fuel consumption and pollution and led to a widespread loss of productive time (Khisty and Zeitler, 2001). While studying its implications on time, space, human freedom and social justice under an ethical, systemic perspective, Khisty and Zeitler (2001) conclude 'that if hypermobility is not dealt with both as an individual and as a collective responsibility, the challenge to transport ethics and its systemicity could be further impaired' (Khisty and Zeitler, 2001).

A second, related notion is that of the *hypermobiles* as a group who travels disproportionately more than other groups, both locally and internationally across means of transport and consequentially has a significantly higher contribution to the environmental impact, as well as the overall mobility demand (Gössling et al., 2009). A distinction can be made between the production-oriented and consumption-oriented hypermobiles. The first describes those primarily travelling for work-related reasons, while the second travels mostly for consumption and leisure. Gössling et al. (2009) studied this phenomenon further based on a travel behaviour study from

France. Some of their main observations of the *hypermobile* cluster were that ‘citizens with higher income levels (over €7,500 per month) are overrepresented in the cluster’, holding ‘management positions and [being] workers with higher education’ in the age group 50-69. Further, singles as well as childless couples, living in Paris, constitute a majority of the group. In numbers of impact, the study showed that 50% of the total mobility related GHG emissions were produced by the 5% hypermobile (Gössling et al., 2009).

While much of this contribution originates from international air traffic and is hence less relevant for the discussion of urban mobility, two conclusions can be drawn. First, a small group has a significant systemic impact. Hence, an in-depth understanding of this dynamic and an accordingly adapted consideration is crucial when assessing environmental impacts of changing systems. Further, the proportional distribution of different mobility behaviours and their development over time will have a significant impact. If globalisation and increasing socio-economic status would lead to a significant increase of the hypermobile population, its impacts of urban mobility futures must be taken into consideration, as well as anticipated and planned for.

Transit-Oriented Development (TOD) and Intermodality

In many ways connected to the discussion on density and mixed-use, the concepts of TOD, multi-, and intermodality shall be outlined. TOD means ‘integrated urban places designed to bring people, activities, buildings, and public space together, with easy walking and cycling connection between them and near-excellent transit service to the rest of the city’ (ITDP, 2020). Combining a variety of urban design and planning principles, it describes the approach to develop urban areas depending on the proximity to mass transit hubs to increase the reach and impact of public transport. In the optimal case, the transit hubs combine a variety of modes (e.g., train, metro, bus). The density shall be the highest around the transit hub and slowly decreasing thereafter. The built environment shall be constituted of varying mixed-use zones, structured by their proximity and target group. The location of specific functions such as public amenities are often integrated to reduce the need for additional stops. The concept is widely applied around the world, mostly shaping the development of rapidly growing urban areas without or with little formalised public transport. However, their applicability and use in areas such as the Île-de-France (IDF) region around Paris remains the same, and hence is also one of the underlying principles of the Grand Paris Express.

Directly linked to the concept of TOD is that of intermodality and multimodality, both referring to the combination of different modes of mobility. Multimodality refers to the use of multiple modes of mobility across different trips (Nobis, 2010). Intermodality adds the dimension of the integrated use of modes of mobility during the same trip⁶. This concept comes with different elements. First and fundamental is the physical intermodality hub (such as TOD) which must provide an effective interface between various modes of mobility. This can, for example, include regional trains, metro, a bus station, as well as bicycle parking/rental, possible connections to micromobility, as well as ride-hailing/-sharing services and sufficient park or waiting areas, all easily accessible, connected, and clearly indicated. Secondly, the different mobility providers need to align their services and allow for seamless transitions. This includes,

⁶ ScienceDirect glossary: <https://www.sciencedirect.com/topics/social-sciences/intermodality> [accessed 12 August 2023]

but is not limited to, the alignment of schedules, shared associated services (e.g., ticket sale/information) as well as collaboration in the payment system (e.g., through shared use of payment platforms, transportation cards, or abonnements). The third and last element addresses some of the above through the use of digital platforms that combine different services, starting from trip planning and going up to payment of different mobility providers. While the latter diverges from urban form, it introduces the next chapter of digitalisation and will be extended on further.

Digitalisation of the mobility sector

The last section moves from the spatial dimension to the virtual, digital field. Digitalisation is probably one of the most significant trends across multiple fields and had global impacts and will continue to do so, very strongly also in the field of mobility. This section describes a few of the trends and concepts considered most relevant for urban mobility futures. However, a very important distinction between digitalisation and technology must be drawn first. We do not describe specific technologies but focus on the overall trend of digitalisation across sectors. Technologies, such as autonomous vehicles, big data, or artificial intelligence, are significant for considerations of urban mobility futures but outside the scope here.

Digitalisation refers to the transition process from analogue to digital and, according to the European Commission (EC), shall lead to ‘more connected, intelligent, efficient, reliable and sustainable’ systems (EC, 2020a). In the urban context, the notion of *Smart Cities* is oftentimes equated with digitalisation. In the beginning, Smart Cities merely referred to the application of information and communication technologies in the urban context. However, this conceptualisation has evolved significantly since and replaced with a Smart City being ‘a place where traditional networks and services are made more efficient with the use of digital and telecommunication technologies for the benefit of its inhabitants and business [...] including smarter urban transport networks, upgraded water supply and waste disposal facilities and more efficient ways to light and heat buildings. It also means a more interactive and responsive city administration, safer public spaces and meeting the needs of an ageing population.’ (EC, 2020b) The ‘Sustainable and Smart Mobility Strategy – putting European transport on track for the future’ was announced by the EC in December 2020 (EC, 2020c) and includes digitalisation as ‘an indispensable driver for the modernisation of the entire system, making it seamless and more efficient [...] to further increase the levels of safety, security, reliability, and comfort, thereby maintaining the EU’s leadership in transport equipment manufacturing and services’ (EC, 2020c).

Zooming further in on urban mobility, Piccinini et al. (2016) categorised findings from a comprehensive literature review on digitalisation in the scope of individual urban mobility in four categories. These are mobility solutions, intelligent mobility infrastructure, partial virtualisation of mobility, and enhanced mobility experience. Associated to each are developments which are partly moving already towards technologies. Some of these are traffic monitoring and regulation, measuring of air quality, noise or air pollution, or responsive lighting, potentially combined in a Digital Twin. The integration of decentralised energy systems adds another layer, in particular relevant for electric mobility and related applications such as Vehicle-to-Grid (V2G) (Gall et al., 2020).

Further, digitalisation shapes the way different mobility providers are interacting, as well as combined for intermodality as introduced in the previous section. For this, the concept of Mobility-as-a-Service (MaaS) and its electrified addition of eMaaS are

important. MaaS aims to optimise the intermodal trips through seamless use, combination, and exchange of platforms with varying levels of service integration. A possible part of MaaS can be the sharing services for cars, bikes, or other vehicles (e.g., micromobility) while they also constitute individually an element of the ongoing mobility digitalisation. Digital services can further provide mobility options which share personal vehicles with others, share hailed rides, or share vehicles for private, individual use. The individual digitalisation of mobility modes and users adds another layer.

Lastly, digitalisation impacts a variety of fields. At this moment, one of the most significant is the global shift to teleworking as partial consequence of the pandemic. Further, the world currently explores and rapidly advances in the organisation of digital events and meetings, which in return decrease the demand for travel. Furthermore, remote education, online (grocery) shopping, as well as an increasing variety of entertainment at home arise, with virtual/augmented reality still at an early phase (Urry, 2016). Each of these developments can have a significant impact but remain highly uncertain.

2.1.5 Selected gaps in sustainable urban mobility

This sub-chapter discussed some of the most important dimensions of sustainable urban mobility and acts as foundation for the subsequent chapters. Two gaps are identified which summarise two of the main challenges which are addressed in this work. Using these as larger contexts, the next part shifts the focus to the methodological responses for advancing the design of sustainable urban mobility solutions in conditions of uncertainty.

Research gaps

Urban mobility constitutes a major contributor with rising role due to ongoing urbanisation but lacks a systematic and localised uptake of people-centred, local, and sustainable solutions.

Urban mobility is subject to high degrees of future uncertainties and lacks actionable modelling to permit a structured integration of uncertainties in design processes.

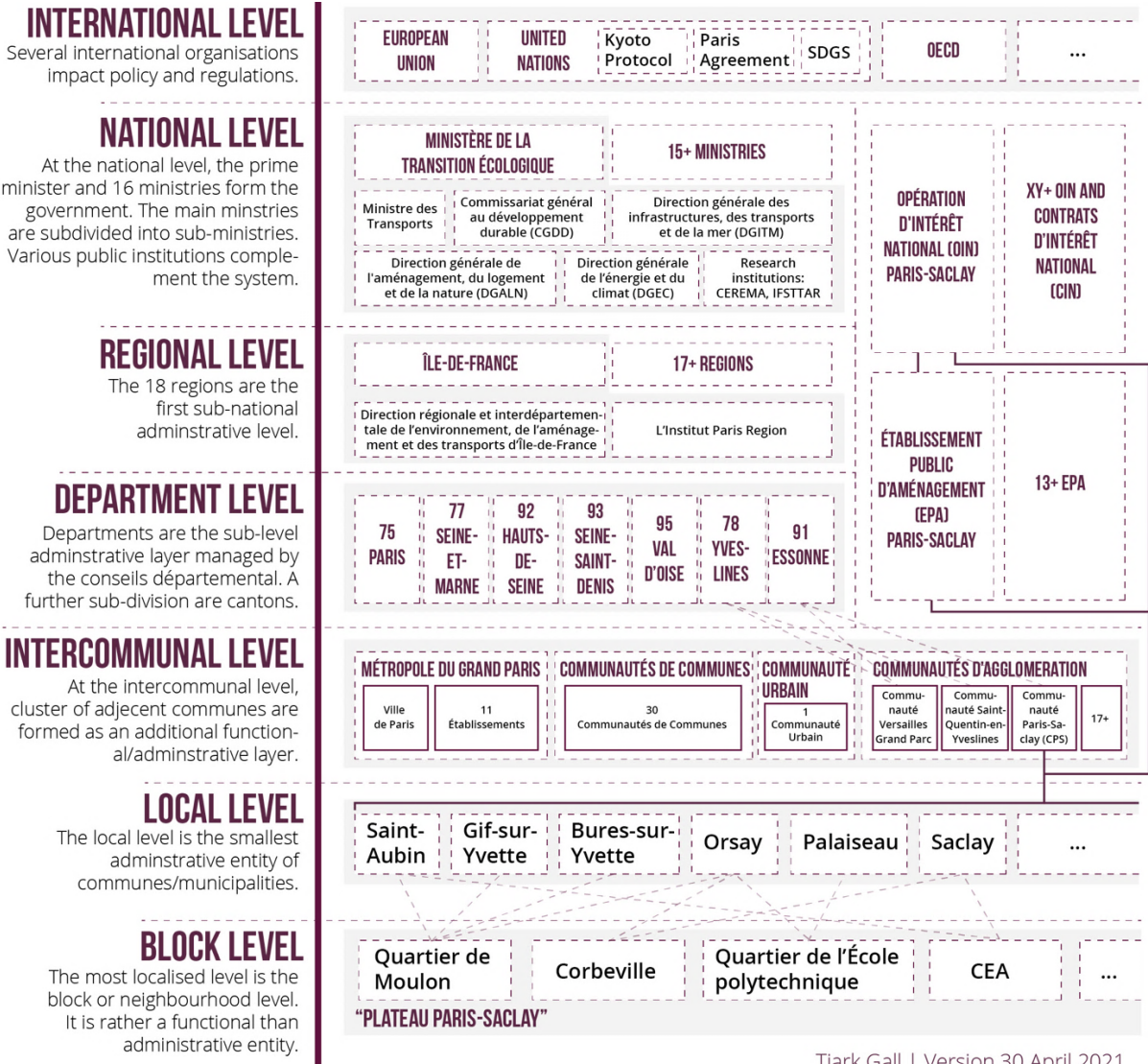
2.2 Designing for uncertain futures

In the second section of the literature review, the focus lies on futures and strategic foresight. First, the current consideration of *futures* and the accompanying *uncertainty* in mobility planning and related policy making is discussed. Next, the field of *futures studies* is introduced which aims to address the challenges resulting from working with uncertainty. After an introduction of the different *pillars of futures studies* provide a conceptual basis for the following sections, the last section zooms in on one of the pillars: scenario-based approaches.

Future uncertainty in planning and policy making

Addressing challenges of urban mobility and implementing policy objectives such as the SDGs or NUA, a diverse set of visions, strategic papers, plans, and policies is created across levels. Figure 5 shows a simplified visualisation of primarily public stakeholders that define parts of urban mobility in the core geographical context of the Anthropolis Chair: the Plateau Paris-Saclay. At the international level, different global and regional institutions establish binding and guiding policies. At the national level, a number of ministries and sub-directions are tasked with the sustainability transition, including a sub-ministry dedicated to transport as well as state-supported

research institutions. In parallel, a number of *operations of national interest*, such as the development of Paris-Saclay as technological innovation cluster, bypass other institutions from national to local level. This involves both planning and participation in decision-making, as well as significant financial flows. Following the regional and department-level, three local levels are involved. Their responsibility and competencies depend on each individual case and are commonly sharing roles in the mobility context. For example, the intercommunal level plans strategic mobility systems, as well as intercommunal mobility, while municipalities are responsible for smaller scales, such as local bike lanes, or local streets. On the block level, public space design, provision of bike parking, charging stations, etc. can be co-defined and implemented.



Tjark Gall | Version 30 April 2021

Figure 5: Administrative layers involved in mobility planning (CC BY 4.0)

The focus of this work is urban mobility. Thus, the most relevant scales are defined as those ranging from local, neighbourhood/block level to the intra-regional level. It appears that most planning of infrastructure and services for mobility are done (with input from the local levels) on the intercommunal, department, and regional level. Hence, *the entry point at the intercommunal level as the intermediary appears sensible to consider cross-scalar links*. Secondly, a broad range of policies, plans, mechanisms, and processes shape the local mobility system. These range from the

international level (e.g., GHG emission reduction targets from the Paris Agreement) and the national level (e.g., nationally determined contributions (NDCs) of Paris Agreement, national legislation), to the ultra-local level with specific policies and plans (e.g., local mobility schemes, bus routes).

The temporal level of a selection of 27 key policies and plans is shown in Figure 6 while a compilation with additional information is provided in Annex AN.4. The futures dimension is extensively addressed primarily in international and national documents, but rarely in local plans and policies. A few documents bridge the scope between planning and visioning, while long-term future elements are either included in a generic manner, or not at all. No place-based or local futures could be identified.

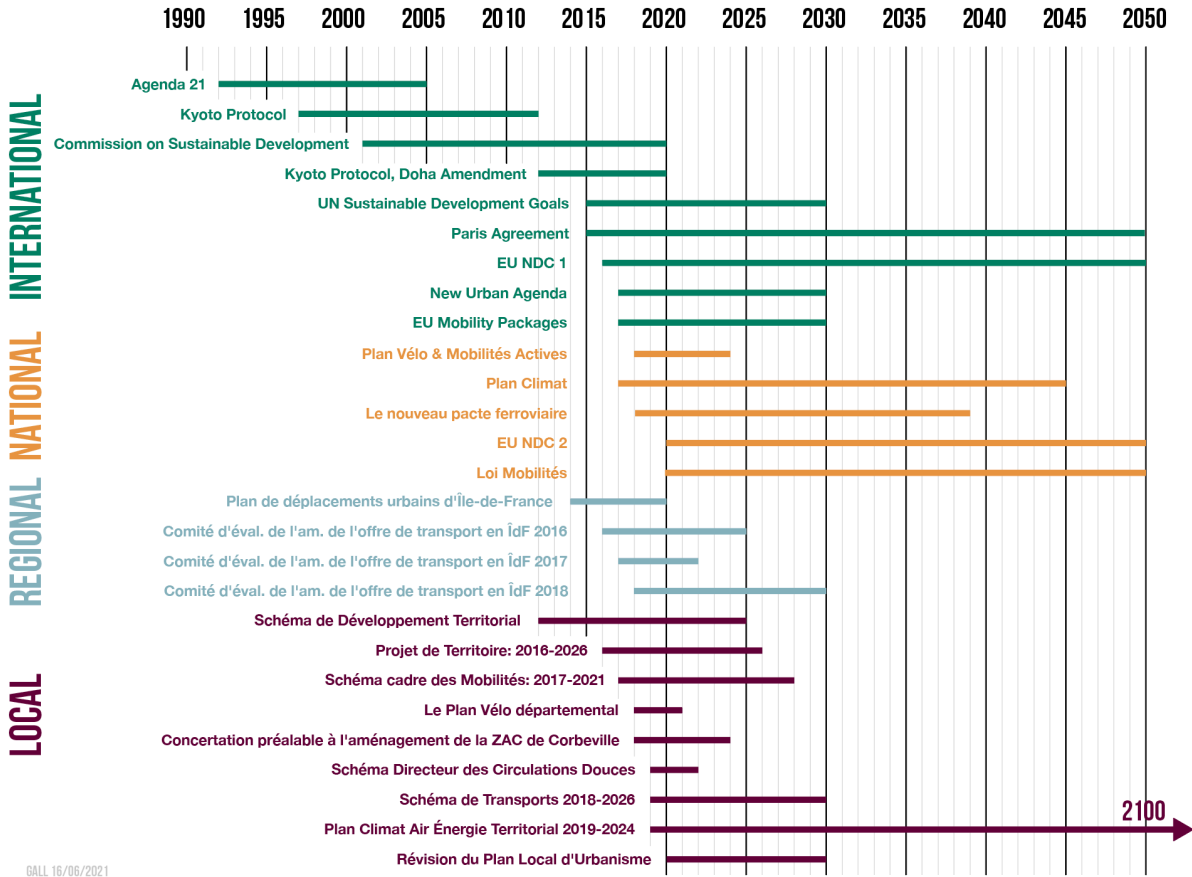


Figure 6: Timeline of policies and their targeted timeframe (CC BY 4.0)

This results in an identified stated importance of considering uncertain futures while simultaneously missing them in local planning and policymaking despite existing methods (Machiels, 2023, Goodspeed, 2020). The sparse consideration of future uncertainty in local planning was matched by primarily general and rarely updated foresight approaches in industrial settings, as identified via scoping interviews conducted with industrial and public sector institutions (see Annex AN.3.2). This motivated deeper research into futures studies and its methods to explore how this could be advanced.

Futures studies⁷

To prepare for, plan, or alter the future, one must understand it first. For centuries, anticipating or studying what comes next has been integral to human societies. References can be found across religions and old scriptures, ranging from future predictions to early ‘futurists’ in the shape of oracles. Despite its early starting point, which attributes can be easily contested, futures studies, futures research, or futurology have gained increasing interest and support since the beginning of the 20th century (Gordon et al., 2020; Fergnani and Jackson, 2019; Dator, 2019). While various contesting positions prevail, some core characteristics of futures studies appear largely established.

First, a non-deterministic, or more precisely, non-pre-deterministic understanding is underlying any normative, transformative, or strategic foresight approach (Amara, 1981). Only if the future is not fully determined through preceding actions, it can be altered and thus justify any attempt to do so. This does not negate the influence of the past and present but highlights the possible modification of the future. Secondly, futures studies are about foresight and not predicting or modelling the future, even if the latter can support foresight. On the other hand, multiple futures can inform decision-makers and help prepare, anticipate, and develop, e.g., robust policies. Thus, futures studies cannot and do not intend to predict what will come next (Inayatullah, 2013; Godet and Durance, 2011).

Jim Dator (2019) argues that ‘the future cannot be predicted because *the* future does not exist’, ‘but alternative futures can, and should be forecast’, and ‘preferred futures can and should be envisioned, invented, implemented, continuously evaluated, revised, and re-envisioned’ and finally, ‘any useful idea about the futures should appear to be ridiculous. [...] what is popularly, or even professionally considered to be “the most likely future” is often one of the least likely futures’ (Dator, 2019, p. 4) or, in other words, ‘the most likely future isn’t’ (Kahn, 1982).

Thus, there is no future but multiple futures with varying likelihoods and levels of preference (Rowland and Spaniol, 2015). Additionally, the *unpredictability and unconventionality of futures studies* are highlighted. This corrects an understanding often mistakenly assumed to be at the core of futures studies: There is usually no likely future; hence the attempted prediction or forecast thereof is prone to failure. Or in other words: Futures studies is not about finding the one likely future, but the *multiple possible futures*. Despite variance within the field, a consensus lies on the focus on foresight instead of forecasting, referring to methods that can identify possible alternative futures and using them strategically instead of trying to predict the future.

Visual aids were produced to explain this and related concepts. A common one is the *futures cone*. It has been in circulation since the early 1990s (Figure 7), with early published versions from Taylor (1993) or Hancock and Bezold (1994). Its basic shape shows a cone with its tip at the current moment and an opening along the temporal axis towards the future, representing a broader range of possible futures. In most cases, the more probable futures are situated in the centre of the cone, and less plausible ones are in the outer areas. Before going into the details of the cones, we expand on the fields of application. Most importantly, the futures cone should not be

⁷ This section contains elements of a paper published in *Futures* (Gall et al., 2021c)

confused with a method to develop scenarios but instead as an aiding visualisation or representation of concepts to be used with other methods (Voros, 2017).

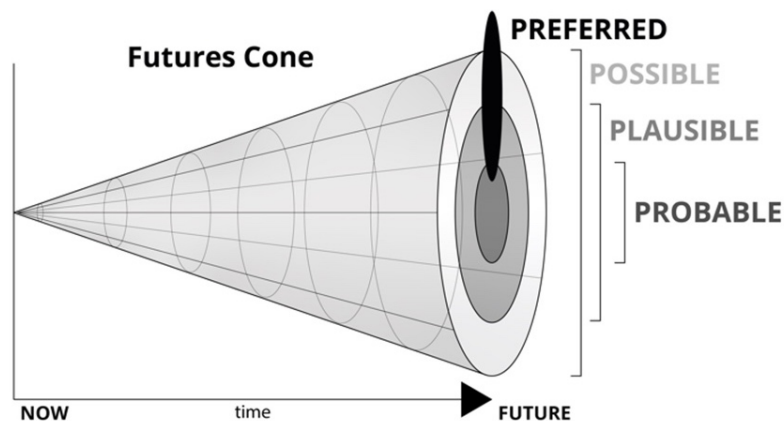


Figure 7: Basic Futures Cone (based on Voros, 2003/2017)

Three key applications of the futures cone are prevalent. Foremost, the futures cone can be used to explain the overall idea behind multiple futures in an ever-expanding possibility space (e.g., Taylor, 1993; Hancock and Bezold, 1994; Voros, 2003, 2017).

Secondly, the futures cone can – in addition to broader futures literacy capacity development – help to contextualise specific components, characteristics, or events during workshops or training that aim to, for example, co-create different scenarios or map trends (Voros, 2017; Garret, 1999; Dunne and Raby, 2013; Levrini et al., 2021). Thus, despite not being a method, it can fulfil the role of explaining and contextualising specific elements. Therefore, making the theoretical context of futures more accessible to the audience (e.g., Levrini et al., 2021). Other possible applications expand into using the cone as a workshop roadmap that showcases steps of the process, an adapted board for gamified applications, or an interactive and 3-dimensional environment in the context of virtual and digital applications.

Lastly, the cone can be a canvas for professional discourse within the conceptual and theoretical domains of futures studies (e.g., Candy, 2010; Christophilopoulos, 2021). Since its first occurrence, the cone has evolved and has been continuously updated and discussed by experts in the field of futures studies (Voros, 2003, 2017; Candy, 2010; Fischer and Dannenberg, 2021). Therefore, its simplicity and graphical-reductionist character allow constant adaptation, evolution, and reconfiguration. Both within the field and in exchange with other domains. Despite its widespread use, there has been little discussion of the various versions, their characteristics, and further development potentials and a *lack of a structured visualisation of futures concepts remains*.

To delve deeper in the underlying theories and concepts underlying the futures cone – a reappearing intermediary design object within this work – we present some of Dator's (2019) principles of futures studies in the following paragraphs. Further, we structure different concepts through the six pillars of futures studies (Inayatullah, 2013). This includes an in-depth discussion of alternative, multiple futures – or in other words, scenarios. Scenarios are defined here as possible and plausible futures, 'taking the proper form of a story or narrative description [...and] exist in sets' (Spaniol and Rowland, 2018, p. 1). We chose this approach to provide a general overview.

Finally, we zoom in on scenario planning as the method most often linked to the futures uncertainty and representation via the futures cone.

Pillars of futures studies

Inayatullah (2013) suggests an organisation of futures studies into six pillars. The first is (1) *Mapping of trends, events, or pushes* – from the past, present and potentially the future. Inayatullah highlights that this is crucial to understand ‘where we have come from and where we are going’ (2013, p. 46). One possible approach is identifying the ‘Shared History’ by collectively mapping trends that resulted in the current moment to identify trajectories and (dis)continuities (Inayatullah, 2013).

While mapping focuses more on the past and present, the pillar of (2) *Anticipation* aims at looking into the future. This can encompass areas of innovation, potential causes of problems, or identifying arising opportunities, as well as potential future disruptors. Comparisons can be drawn to the concept of weak signals (Börjeson et al., 2006) from fields such as innovation design, niches from transition theory (Geels, 2011), lead users, referring to the early adopters or ambassadors of products or services (von Hippel, 2005), or first followers from social behaviour studies.

Further, the pillar of (3) *Timing* describes the identification of patterns of change and its stages, hence deriving assumptions of future behaviours from it (Inayatullah, 2013). This can be found extensively in financial markets or climate studies. Inayatullah names three possible behaviours: (1) Stage-like linear futures; (2) Cyclical futures with ups and downs; and (3) Spiral futures. In the context of the latter, he also refers to the fact that futures are often ‘driven by a creative minority’ (Inayatullah, 2013). He points out that there are brief moments in human history with significant potential global impact, the current period being such (Inayatullah, 2013).

The fourth pillar is about (4) *Deepening the future* through, e.g., Causal Layered Analysis. Inayatullah (2013) identified four layers: 1) Litany, 2) System, 3) Worldview, and 4) Metaphor. Litany (day-to-day future) is the surface-level, daily and short-term future image. The second layer looks at systemic elements such as the issue’s social, economic, or political causes. In the third layer, the culture or worldview are addressed, referring to the big picture, or the paradigm that defines the real or not real and accompanying ‘cognitive lenses we use to understand and shape the world’ (Inayatullah, 2013, p. 52). The last dimension is the narrative or the myth or metaphor. As deeper changes go, the longer the transition takes, the less tangible and quantifiable changes become.

The fifth pillar focuses on methods to (5) *Create alternatives, or more precisely, alternative, multiple futures*. The most widespread associated methodology is scenario planning. In Inayatullah’s words, scenarios ‘open up the present, contour the range of uncertainty, reduce risk, offer alternatives, create more flexible organizational [sic] mindsets, and even better, they predict’ (Inayatullah, 2013, p. 54).

The sixth pillar is about (6) *Transforming*. Futures studies often intend to take a transformative role, either indirectly or directly. This can range from directly impacting the future to reaching a specific goal or transforming the current situation to prepare for potential future shocks. Inayatullah distinguishes between three types of transforming: Visioning, backcasting, and transcending. Visions can be an integral element of scenarios, mainly in the case of the normative notion. Visions aim at bringing people together in a shared perspective of a positive future and inspire, push, and impact behaviours. Visions can be found across fields, including company

visions, as well as from the public sector (Tanum et al., 2020) or in broader practical fields (e.g., UN-Habitat, 2012).

If a vision has been identified, backcasting (the reverse of forecasting) can be applied to see what would need to happen and which actions would be needed to be taken to reach the preferred future (Dreborg, 1996). As Inayatullah (2013, p. 58) phrases it, 'backcasting fills in the space between today (the future) and the past' and transforms abstract futures into actionable insights. The latter can inform strategic planning processes and policymaking or build the basis for strategies and action plans. The last element for transformative purposes is transcending. This approach can be applied if two (or more) contesting futures or future trends exist. Instead of looking for an in-between or compromise, contesting elements are identified and attempted to be combined into a new, mutually benefitting scenario (e.g., Green Growth; see Inayatullah, 2013).

Scenario planning

In this section, we zoom further in one of the pillars, namely that of creating alternatives as the most relevant one for this work. With early applications by the military through the think tank RAND (Kahn and Wiener, 1967; see Abella, 2008 for an extended overview) and Shell (1971) in the 1960s, scenarios started as a tool to prepare countries and businesses for (future) trends or shocks (such as the 1973 oil crisis). They were quickly taken on by other sectors and think tanks around the globe.

Today, we can find scenario-based approaches in a variety of domains, ranging from spatial planning or innovation management to public administration (Budman and Khan, 2018). In the case of strategic foresight, scenarios can be used as one of the alternative-building methods of futures studies. Scenarios can inform and guide decision-makers by creating normative, descriptive, or exploratory alternatives, expanding cognitive limitations from bounded realities and formulating relatable and plausible future narratives (Crawford, 2019; Weidema et al., 2004; Lincoln Institute, 2020).

Parson et al. (2007) describe scenarios as stories that narrate potential futures and the process to get there, thus fulfilling various purposes, such as informing decision-making. Further, they state a few key determinants of scenarios: 1) They are 'holistic (i.e., multi-dimensional), 2) schematic, 3) come in sets of two or more, and 4) claim less confidence than other types of future statements' such as simulations or extrapolations (Parson et al., 2007). Further, Van Notten et al. compiled various characteristics for future scenarios, grouped into 1) Project Goal, 2) Project Design, and 3) Scenario Content (Van Notten et al., 2003). The project goal or purpose of scenarios is broad, ranging from creating alternative pathways, allowing for imagination (sometimes strengthened by personas⁸), or creating fear/urgency or hope (visions).

Further, they can support the testing of assumptions of impacts of today's decisions, make policies 'future-proof'/robust, or inspire, enable, or enforce product, service, or policy design. Scenarios can be rational/objectivist, e.g., through the cross trends impacts approach, or social constructivist, e.g., through the approach inherited and developed by the Shell Intuitive Logics school of scenarios (van der Heijden, 2004; Wack, 1985a; Wack, 1985b). Finally, they can be normative/deterministic, e.g., as

⁸ Archetypical representations of categories of people to make them more tangible (Cooper, 1999; Vallet et al., 2020).

developed by the school of La Prospective (Godet and Durance, 2011; Wilkinson and Eidinow, 2008; Crawford, 2019; Weidema et al. 2004).

Different classifications have been developed to organise the various approaches that evolved in scenario making. For example, Crawford's (2019) classification focuses on the objective behind the use of scenarios. She distinguishes between two main types of predictive scenarios (what will happen?). These are forecasts looking at what will happen as the probable developments occur. Further, normative scenarios (what can happen?) are concerned with achieving future objectives. The latter comes in two sub-categories, mainly preserving and transforming scenarios (cf. Wilkinson and Eidinow, 2008).

The resulting scenarios are often labelled. These labels range, for example, from possible, plausible, and probable (the '3-Ps') to preferred (or preferable) and likely scenarios (Henchey, 1978; cf. Voros, 2017). While the term 'preferred scenario' is often followed by the questions of being preferred by what standard and by whom, defining one or several preferred scenarios is necessary if a normative notion is followed (Godet and Durance, 2011; Goodspeed, 2020). The earlier introduced term of (most) likely scenario is still used but contradictory due to the discussed challenge of predicting the future. A similar and widely used term is the Business-as-Usual (BAU) scenario which overlaps with the contestable notion of a predicted or likely scenario (Dator, 2019; Godet and Durance, 2011). Both terms are primarily used when projecting or extrapolating an individual future, opposing partially the underlying concept of utilising multiple futures.

While various types of methods are linked to working strategically with the future. These include, for example, scenario planning, trend analysis, expert-based methods such as Delphi, environmental/weak signal scanning, causal layer analysis, or technology scouting. *Scenario planning* is one of the more common ones. In practice, such scenarios are, for example, used to prepare businesses or public entities for changing conditions and needs of uncertain futures, to explore viable pathways to sustainable futures, or to inspire designers and innovators to develop new solutions for new markets.

The objective is usually to respond to the overarching challenge if dealing with future uncertainty when taking design decision. This means *what can or must we know and consider that we cannot be sure of*. This excludes primarily elements that we are sure of to remain stable (e.g., the sun will continue to provide solar energy potential at similar levels) as well as developments that we assume, depending on the timeframe, nearly certain (e.g., a continued demographic process of ageing in France). We refer to these as *trends*.

What remains are *uncertainties*, used only to refer to *future* uncertainties throughout this work. These can also be called *critical uncertainties* if their development has a potentially high impact on the application context. For example, how many people will move into a newly developed suburban area by when, or how far advanced will automatised vehicle technology be by 2030? Another common term is that of deep uncertainties, referring to uncertainties that have a likely systemic impact and are complex in nature (Helmrich and Chester, 2019). These have been Courtney et al. (1997) in four levels: 1) A clear enough future, 2) Alternate futures, 3) Range of futures, and 4) True ambiguity.

Finally, the terms of unknown unknowns and black swans are used to refer to non-imaginable future developments (e.g., new technology developments not thought of

yet) or those which can be imagined but are not considered possible. Finally, we must make a clear distinction of methodological uncertainties, e.g., those of modelling or prediction frameworks. While sharing the same name and sometimes being relevant in quantitative futures work, they are not referred to herein.

The focus of scenario-based strategic futures approach is often addressing critical, deep uncertainties and only in exceptions try to integrate unknown unknowns or uncertainties. ‘A clear enough future’ does not require uncertainty-addressing approaches and can be equalled with ‘known’ future developments or trends. ‘Alternate futures’ are foremost one against another or bifurcation points. E.g., does a war happen or not?

In contexts such as the application field of UMSs, many developments happen in parallel, making such a clear distinction impossible. What remains are primarily ‘Ranges of futures’ (e.g., assuming a future population between 10 and 14 M people), thus critical uncertainties that appear on a scale, as well as ‘True ambiguity’, e.g., a German government dominated by green or liberal powers with diverging policies and decisions.

Earlier, local future considerations and scenarios were identified as missing in the context of Paris-Saclay. On the other hand, a large range of generic or *archetypical scenarios* can be identified. Archetypical scenarios refer to recurring themes and patterns that are common for many scenarios and permit a classification of existing combinations of trends and uncertainties (Dator, 2019; Fergnani and Song, 2020). Such archetypes are prevalent across sectors, including urban mobility. Miskolczi et al. (2021) identified four types of scenarios in urban mobility scenarios until 2030:

1. *Grumpy old transport*, referring to continuation of current developments.
2. *At an easy pace*, implying a slow but constant sustainability transition.
3. *Mine is yours*, referring to a continuing rise of sharing practices.
4. *And tech-eager mobility*, highlighting the dominating role technology could take.

The use of such archetypes or international or national scenarios on a local scale appears promising. However, we identified *a lack of methods to adapt archetypical scenarios to local contexts*.

2.2.1 Selected gaps when designing for uncertain futures

Research gaps

While actionable methodological frameworks exist to work strategically with future uncertainties – notably scenarios – a conceptually coherent visualisation approach is missing to enable its integration and wider uptake in planning and design practice.

Many suitable scenarios already exist, oftentimes falling in archetypical categories. However, an approach to evaluate the adequacy of existing scenarios to reuse and localise them to the socio-geographical context is missing.

2.3 Designing solutions for future urban systems and urbanites

Thirdly, we review key theories and concepts regarding design for future urban systems and urbanites, building on the previously introduced futures concepts and scenarios. Before delving into this, two clarifications on the used vocabulary. First, a distinction between *design* and *planning*, especially in the urban context. Secondly, a clarification of the notion of *decision-making* in this work.

In the urban context, we commonly refer to urban design, strategic, regional, territorial, spatial, or urban planning. Some of these terms are commonly used interchangeably or differently across countries and languages. The author attempts to delineate some of them from his own professional perspective to clarify what is meant with them in the context of this work. *Strategic planning* refers to a larger, conceptual approach of planning, often at higher conceptual and spatial level and without precise spatial interventions (Fioretti et al., 2020). *Regional, territorial, and urban planning* are referring to more traditional *spatial planning*, their use depending on a mix of the concerned spatial scale, the country-specific administrative setup and competencies attributed to the planning authority, as well as the term user's subjective stance. *Urban design*, on the other hand, refers to smaller scale design of urban layouts, linking the scales of planning and architecture, and mostly finding application in new neighbourhoods or public space developments.

Outside the planning context and on a general level, design and planning are rather understood as *different process stages*. Design focuses on the conceptualisation and definition of a preferred status of an artefact of whatever kind. Planning refers to process of implementation or realisation. Within this work, we refer predominantly to the latter definitions and focus on *design*. Using the disciplinary lens of *design science*, we understand design as large umbrella term, building on the idea that everything can be designed, including policies, services, products, or product-service systems. Designing implies taking decisions, for example to choose between design variants or between different interventions or solutions⁹. When reference is made to decision-making, this is solely situated as part of design processes and not as the independent field of study of the same.

Decision-making is usually considered within design processes as a process of rational decision-making where the best design alternative with the best expected performances is selected. Yet, Simon (1983) explained through the *bounded rationality principle* that humans are incapable to consider all possible alternatives and all uncertainties, due to the complexity, amount of information, and lack of knowledge of past, present, and in particular the future. Thus, 'satisficing' is used as an activity that tries to balance between *information available and needed* to take a decision.

Most of the time spent before making design decisions are about searching for facts and values. Within individual stakeholders, we can define a normative position that predefines values. However, when considering a multi-stakeholder context, these values are most likely competing, thus leading to a *wicked problem* (Simon, 1983; Rittel and Webber, 1973). Common examples are the trade-off between environmental and economic benefits, or even navigating between reducing emissions and enabling minimum accessibility to opportunity for everyone. Additional to potential challenges of multi-stakeholder contexts, we cannot take everything into consideration but must reduce the complexity of reality to a manageable degree. This can be referred to as 'bounded rationality', meaning the prioritisation of relevant present challenges (Simon, 1983). Finally, emotions can play a significant role in decision-making (Simon, 1983, p. 29). For this reason, making future states experienceable (Garduño García and Gaziulusoy, 2021) is seen as a crucial component of working with scenarios. The most common element used are narrative descriptions, as well as artefacts that can support the user's connection with the

⁹ Interventions and solutions are used predominantly interchangeably throughout this work.

narrative. These can artefacts include personas (Vallet et al., 2020), visualisations, or objects (Candy, 2010).

Building of this overall framing of design and decision-making within, as well as the conceptual link to scenarios, we zoom in on the design for people in general and design of mobility solutions for future urbanites.

2.3.1 People-centred design¹⁰

A variety of design methodologies interacting in some way with humans can be grouped through People-Centred Design (PCD). The term is constituted of the meaning of the word – design with people, or human characteristics at the core, complemented with the definition of being foremost a non-linear, impact-driven approach and process which solves problems by involving humans in the process and creating outcomes which are responding to the human's expectations (IDEO, 2015).

Multiple approaches have been developed, such as user-centred, human-centred, people-centric, inclusive or participatory design. They are applied across various design disciplines such as product and service design, architecture, or urban planning. Yet, they vary significantly in their characteristics and consider people to varying degrees and with different methods.

This section provides an overview of existing approaches from the design and planning field and an initial classification. The extended definition and description of each type can be found after the classification. The focus lies on approaches directly linked to a varying level of interaction or influence on humans. We group methods with similar approaches and use to the most common name. Existing classifications and frameworks are the foundation for the following (Sanders and Stappers, 2008, 2014; Buur and Matthews, 2008).

Most notably, Sanders and Stappers (2008) developed a matrix divided into 'led by design' vs. 'led by research' on one axis and 'user as subject' vs. 'user as partner' on the other. User-centred design approaches are situated on the passive, research-led side, encompassing usability testing, human factors and ergonomics, applied ethnography, lead-user innovation, and contextual inquiry. On the other hand, participatory design research falls onto the active side, including generative design research and 'Scandinavian.' The latter refers to one of the first participatory practices centred around 'deep commitments to democracy and democratisation; discussions of values in design and imagined futures; and how conflict and contradictions are regarded as resources in design' (Gregory, 2003).

Building on their categorisation, the following classification utilises two parameters which are described below. One focusses on the impact on different types of humans, the second on the level of participation in the design process. The individual human is put at the centre for both.

For the context, we identified people of three types. First, the 'user human' (or group thereof) who is the product or service's user and can be an active stakeholder of the design process. Second, the 'non-user human', which is part of the same immediate

¹⁰ Parts of this chapter were published in: Gall, T., Vallet, F., Douzou, S., and Yannou, B. (2021). Re-defining the System Boundaries of Human-Centred Design. *Proceedings of the Design Society*, pp. 2521-2530. <https://doi.org/10.1017/pds.2021.513>

society, referring to the group of humans in a homogenous spatio-temporal context. The second may be exposed to the impacts of the designed product or service. In some cases, the latter may also be indirectly involved through, e.g., surveys whose outcomes inform the final product but whose participants do not become users themselves. Third, the 'distant human' which is part of humankind but not of the direct society. This can be distant in time and/or space. The group of the first two types, including users and non-users, constitutes the society. Combined with the latter, this is referred to with humankind in Figure 8.

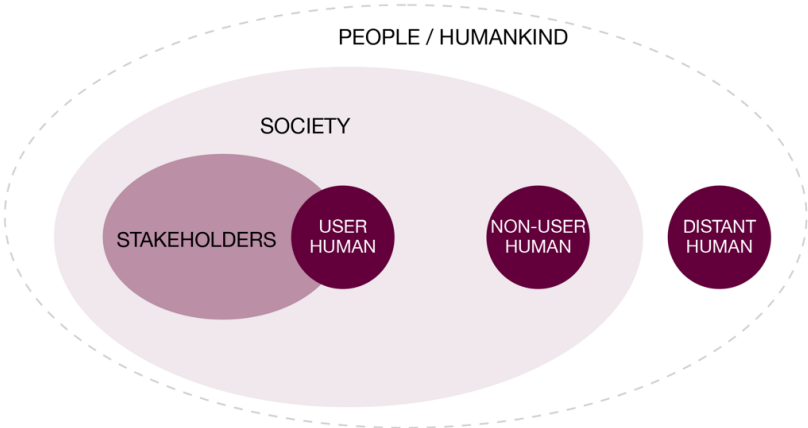


Figure 8: Relation between types of humans, society, and people (adapted from Gall et al., 2021b; CC BY 4.0)

The second dimension of classification addresses the level of participation in the design process as proposed by Sanders and Stappers (2008). This is relevant for two reasons. First, the definition of PCD focuses on the integration of humans in the process as a core element. Second, the level of participation of humans may relate to the impacts of the product or service and is, therefore, central for the purpose of this paper. Hence, we categorise the approaches ranging from no participation to co-creation, and finally decentralised design (users design independently, described in detail below).

Building on these two categories, Figure 9 portrays the different PCD approaches. The x-axis portrays a qualitative assessment of the different approaches' range of impact on humans, ranging from the user human on the left, to humankind on the right. On the y-axis, it shows the range of typical levels of participation, ranging from no/low participation to high levels of participation.

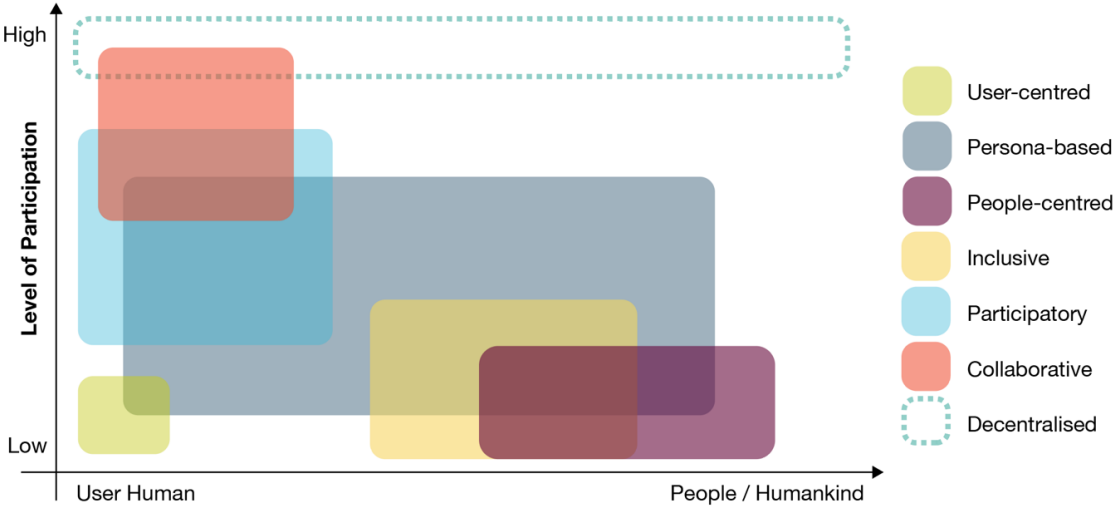


Figure 9: People-centred design approaches (adapted from Gall et al., 2021b; CC BY 4.0)

While the arrangement in Figure 9 is not irrefutable, it can lead to three observations: 1) More active HCD processes are likely to focus on impacts on user humans; 2) Approaches more focused on humankind are less likely participative; 3) None considers fully the impacts on humankind, even less so from the more participatory approaches. Excluded from this is decentralised design, which is most participative but does not necessarily consider anyone but the designing human itself. Yet, if everyone has the same capability of designing for themselves, it could lead to a democratic representation of each human, hence humankind at large. However, as it is not a widespread method, it cannot be fully considered. To expand on the characteristics, the following section describes and compares the methods.

User-Centred Design

User-centred design can be defined as ‘an iterative design process in which designers focus on the users and their needs in each phase of the design process’ in which ‘design teams involve users throughout the design process via a variety of research and design techniques, to create highly usable and accessible products for them’ (Interaction Design, 2020). The approach is often linked to user interface design and other sub-fields which intend to be responsive and/or predictive, e.g., through the use of market analyses or weak signals. The approach can be supplemented by concepts such as future users (Gregory, 2003), lead user/early adopters/lighthouse customer (Buur and Matthews 2008), or methods such as customer journeys. Empathic or compassionate design add an additional dimension (Seshadri et al., 2019).

Persona-Based Design

Another approach, building on user-centred design, is persona-based design. Personas are fictitious characters that represent a homogenous class of users (Cooper, 1999). Future personas allow representing users in a prospective mode and are characterised by 1) a user model, (2) a communication tool, 3) a decision aid and prospective tool (Bornet and Brangier, 2013). Usually, a persona is given a name, a visualisation, and a narrative that provides input on attitudes and behavioural traits (Adlin and Pruitt, 2010). This allows the persona to come to life and become embedded in the designer’s creative process (Cooper, 1999; Grudin and Pruitt, 2002). Methods to create personas can be grouped in three approaches (Salminen et al., 2020). First, fictional elements can be completed with qualitative data. For example, Goodman-Deane et al. (2021) created personas by combining data from questionnaire and interviews. Second, personas can be created from fictional elements (Vallet et al., 2020). A mixed-method approach is used to create tangible futures and match qualitative mobility user personas with scenarios. Third, recent approaches are using big data leading to data-driven personas (see Persona generator, Stevenson and Mattson, 2019).

Personas create a foundation for discussion between designers and clients and prime them for deeper immersion in varying user profiles that differ from their own socio-economic profile, contributing to more inclusive design (Grudin and Pruitt, 2002). When designing mobility solutions, personas were used to feed the emotional design of autonomous shuttles (Kong et al., 2018) or the design of a ride-sharing service (Gargiulo et al., 2015).

People-Centric Design

People-centric design is a variation of user-centred design with a stronger focus on the people and the public perspective. It originates from the field of urban design,

spearheaded by Danish architect and urbanist Jan Gehl (2011) in the 1960s. He studied public spaces in Italy through a multi-disciplinary lens, leading to a renaissance of concepts such as human-scale and human-friendly cities in times of car-dominated urban transformations. His work constituted the European pendant to Jane Jacobs' (1961) pioneering work to re-focus cities on people through a list of recommendations which remain valid until today. Since then, conceptual subsidiaries arose, e.g., child-friendly design. In a broader sense, people-centric design can be grouped with design anthropology (Buur and Matthews, 2008).

Inclusive Design

Inclusive design highlights that each 'design decision has the potential to include or exclude customers' and focuses on 'the contribution that understanding user diversity makes to informing these decisions' (University of Cambridge, 2020). While often used to design for people with disabilities, this would be more accurately accessible design. Further, inclusive does not equal inclusionary design. The former allows everyone to participate, whereas the latter refers to prioritising the diversification and consideration of unique groups. Compared to the previous approaches, inclusive design shares many similarities but adds the importance for individuality in observing and including people's needs in design processes to reach good outcomes for all groups.

Participatory Design

Participatory design refers to design processes in which the user directly participates. This can manifest in a variety of ways, from short opinion surveys at the start of the process to an ongoing consultation. Other concepts with a similar meaning are citizen/user/stakeholder engagement, among others (Bertolini 2020). While participatory design is centred on the active involvement of people, the design process remains separate and only informed by the participation process. Therefore, participation can sometimes become a mere box to tick or mandatory element without integration of the results in subsequent steps.

Collaborative Design

The next level of active involvement is co-design, co-creation, or co-production. The prefix 'co' refers to collaborative, or the simultaneous, open, and horizontal collaboration between designers/experts and users/citizens. Extended conceptualisations thereof include the co-production as part of co-creation, e.g., through storytelling (Gall and Haxhija, 2020), or practices of mediation, negotiation, and consensus finding (Watson, 2002, 2003). While it goes under various names, co-design and co-creation found widespread use and are often jointly developed with initiatives towards open science, citizen science, or citizen observatories. While the user plays a significant role, the designer remains a central figure as facilitator, mediator, or translator (of knowledge) (Sanders and Stappers, 2008; Verloo 2019).

Decentralised Design

Lastly, and less formally defined, an approach of decentralised design has been added in response to current trends such as decentralised or newly re-localised production as well as the concept of prosumers (acting as both producers and consumers), enabled by new technologies and values (Rifkin, 2011; cf. Kropotkin, 1902). The proposed addition describes a process in which no designer or external expert is actively involved in. The role of a facilitator is rendered substitutable, for example due to improved interaction with machines through simplified processes.

While this does not apply in many cases yet, it might in the future. A common example is the potential of decentralised design and production enabled through 3D-printing (Urry, 2016). However, decentralised design describes a field broader than the existing maker movement and other initiatives that evolved around 3D printing. When imagining design approaches of the future, the concept of post-automation can add another layer, describing the period where most essential functions would be automatised and people at large would have access to design and production facilities, an abundance of time and interest or even need to create and produce artifacts.

Another analogy can be drawn to approaches such as bottom-up, community-led, or grassroots design (Seyfang and Smith, 2007). Compared to approaches by larger organisations or institutions, they start like decentralised design on a very small local scale. However, they intend to scale up. This can be seen as a variation or potential consequence of decentralised design, which in itself just focuses on the design process of an individual for an individual or a very small group (such as the family).

Discussion of methodologies

Comparing the seven design approaches described, they all interact with people, even if in different manners. Some address the human primarily as user and intend to increase the understanding of expectations and needs, while others involve the human actively in the design through participation, co-design, or even by becoming the designer themselves. Important are two key characteristics:

- 1) *While all have relevant key characteristics, none of the described methods can be seen as holistic and tick all boxes. Thus, in most cases choosing one does not suffice.*
- 2) *None of the main approaches (excluding decentralised design) considers impacts on user humans, non-user humans and distant humans simultaneously.*

Concludingly, the term of people-centred design is understood as referring to the overall field of approaches and acknowledge the challenges of working with people across time and space – especially relevant in the futures context. Further, we point out the complementarity of different methods within PCD, resulting in the need to choose and combine complementary approaches depending on the project context.

2.3.2 Mobility solution design

After the discussion of PCD approaches for the design process, we focus on *what* is designed. To obtain an overview of what types of solutions can be conceived in the urban mobility context, a solution database has been created (excerpt in Figure 10). The full database is available online¹¹ and its key information is provided in Annex AN.5.

¹¹ Accessible at: <https://urban-mobility-futures.notion.site/3b4cb3e4fccd48a38cda6149a0d6ffa1?v=3874c176a916482faa2e246a18890daa&pvs=4>

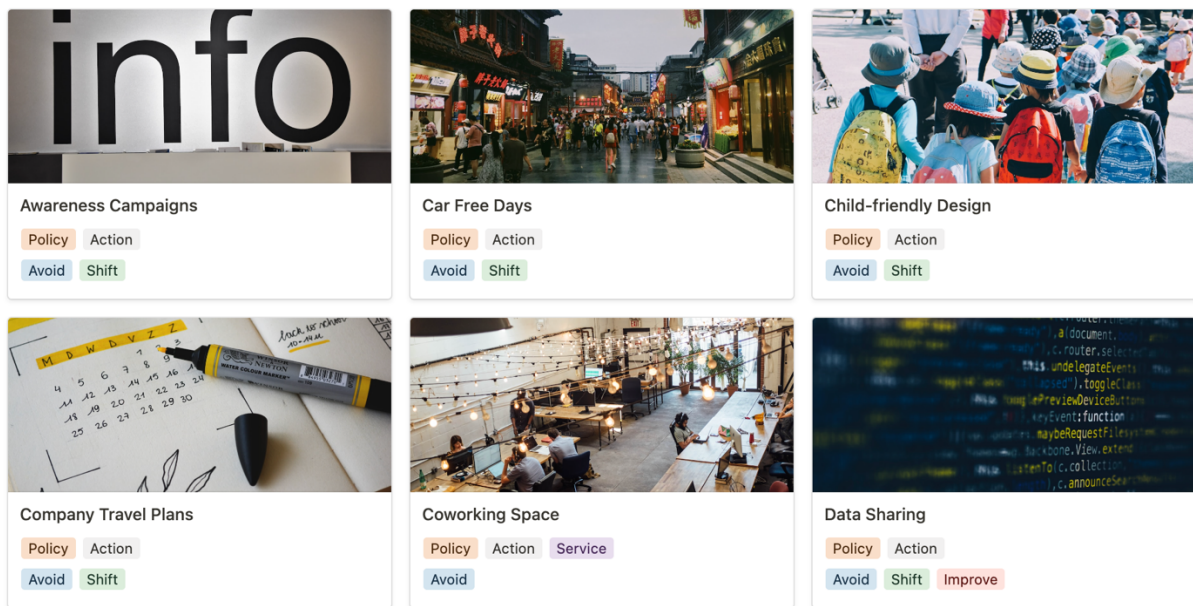


Figure 10: Excerpt of created urban mobility solution database

The solutions include various types such as products, services, and policies, and a large set of involved stakeholders. The design of such mobility solutions may aim for diverse objectives. However, while most of them are aiming to contribute to sustainable urban mobility, it can be challenging to understand the impact they can have, even more so when the contextual factors change as well due to a longer future perspective. Some might aim for a reduction of CO₂e emissions to a specific level or ensuring that everyone in a specific area has a level of accessibility that permits reaching core functions, such as educational facilities, supermarket, hospitals, and a percentage of the job opportunities of the area within a specific time without relying on personal internal combustion engines (ICE) vehicles.

The challenge to measure mobility solution impacts can be emphasised by quoting economics Nobel laureate Angus Deaton: ‘The need to do something tends to trump the need to understand what needs to be done. And without data, anyone who does anything is free to claim success’ (Deaton, 2013).

Different types of data-driven models are currently used to analyse and model current and future UMS states as well as the impacts of existing or potential future mobility solutions. The most common one is the 4-step-model, a trip-based model used since the 1950s. By looking at the 1) Trip Generation, 2) Trip Distribution, 3) Mode Split, and 4) Traffic Assignment, linear estimations can be made on future mobility demand (McNally, 2007). Less frequently used but more powerful are Land-use/Transport Interaction (LUTI) models which can look at multi-directional interactions between land-use, demand, and transport offer evolutions (Geurs and van Wee, 2004).

More detailed observations on interactions are enabled by activity-based models such as agent-based models. They are particularly powerful when dynamic effects such as congestion, shared mobility services, and occupation rates, or detailed perspectives on individuals are of interest. As this work applies a people-centred perspective, the latter approach is prioritised to enable the integration of future uncertainty and variations of tomorrow’s urbanites on the UMS.

A key element within such agent-based simulations supporting urban mobility solution design are *synthetic populations* (SP). Different to personas, SPs aim to statistically reflect a real population (Ramadan and Sisiopiku, 2020; Hermes and Poulsen, 2012).

SPs represent reality via individuals, often grouped into households. Sociodemographic attributes are assigned to the individuals. Various approaches have been created to generate these. Some are based on statistical fitting algorithms (Durán-Heras et al., 2018; Yameogo et al., 2021) and generate individuals so that specific attributes such as age or income classes are distributed in line with reference distributions to preserve spatial heterogeneity. Others use disaggregated, sparse data sets such as household travel surveys. These can be described, for example, by using Bayesian networks (Sun and Erath, 2015) or Hidden Markov Models (Saadi et al., 2016). Further, recent approaches join multiple sources of information through machine learning and deep generative modelling (Borysov et al., 2019; Saadi et al., 2018).

SPs can be useful to model mobility patterns, e.g., to test potential future services or impacts of policy decisions by modifying the schedules of the agents (Hörl et al., 2019), estimating changing GHG and noise emissions (Le Bescond et al., 2021), or assessing policies (Panos and Margelou, 2019).

2.4 Existing works on future urbanites

Some works exist that target structured design or simulation of urban mobility users. For example, Al Maghraoui et al. (2019) developed a qualitative approach to model the experience of mobility users. On the other hand, Kamel et al. (2019) and Vosooghi et al. (2019) created quantitative approaches to measure and integrate preferences, values, or other individual attitudes into data-driven approaches in the mobility context. For the direct work with futures urbanites, conceptual links between personas and synthetic populations have been identified in the past (Vallet et al., 2022) but have not been applied jointly in the context of urban mobility to the authors' knowledge. Building on the existing methodological components and the existing scientific contributions, some promising gaps have been identified. First, most qualitative design approaches do not permit to adequately integrate quantitative characteristics. Additionally, many data-driven approaches lack systemic approaches to integrate qualitative trends due to the need to transform the information. Further, a challenge shared across persona and SP-based approaches, only few works have attempted to integrate future changes of users and populations into the approaches. These approaches are either addressing one specific dimension (e.g., population growth) or scaling up the present in some way. Consequently, research gaps and potentials are identified to integrate differences across user groups in simulation.

2.4.1 Selected gaps for people-centred solution design

Research gaps

Current design approaches prioritise users and human characteristics but lack the consideration of people across time and space.

Two dominating people-oriented methods in qualitative and quantitative approaches, personas and synthetic populations for agent-based simulations, lack an integrated approach and, in case of the latter, a method to integrate future uncertainties.

2.5 Research gaps and research questions

Combining the context and motivation of this project and the reviewed literature, several research gaps resulted that address the three main objects of research: The *modelling of future urban mobility systems*, the *strategic work therewith via scenarios*,

and the *localised and transdisciplinary integration in actual design or design support processes* for sustainable and people-centred urban mobility solutions.

More in detail and echoing the above-mentioned research gaps, the first two research gaps are overall ones that origin from the field of application and are central to all subsequent work but are only partially addressed through this work:

1. Urban mobility constitutes a major contributor with rising role due to ongoing urbanisation but *lacks a systematic and localised uptake of people-centred, local, and sustainable solutions*.
2. Urban mobility is subject to high degrees of future uncertainties and *lacks actionable modelling* to permit a structured *integration of uncertainties* in design processes.

Next, we identified two conceptual gaps situated in the field of futures studies:

3. While actionable methodological frameworks exist to work strategically with future uncertainties – notably scenarios – a conceptually coherent visualisation approach is missing to enable its integration and wider uptake in planning and design practice.
4. Many suitable scenarios already exist, oftentimes falling in archetypical categories. However, an approach to *evaluate the adequacy of existing scenarios* to reuse and *localise them* to the socio-geographical context is missing.

Finally, two methodological research gaps result from the quest to contribute to people-centred design:

5. Current design frameworks prioritise users and human characteristics but lack the consideration of *people across time and space*.
6. Two dominating people-oriented methods in qualitative and quantitative approaches, personas and synthetic populations for agent-based simulations, lack an integrated approach and, in case of the latter, a *method to integrate future uncertainties*.

The resulting updated research questions are as follows. An overarching research question remains, complemented with a number of detailed research questions for the identified research gaps.

Research questions

Main RQ: How can design processes of people-centred mobility solutions for future urban systems be supported?

Supporting RQ 1a: How can urban mobility systems be modelled?

Supporting RQ 1b: How can urban mobility system futures be modelled?

Supporting RQ 1c: How can future urbanites be modelled?

Supporting RQ 2a: How can future scenarios be localised?

Supporting RQ 2b: How can future uncertainties be integrated in synthetic populations?

Supporting RQ 2c: How can future uncertainties be integrated in agent-based simulations?

These six research gaps and research questions, grouped in three categories, constitute the structuring element of the proposed contributions. The next chapter on the research methodology describes the grounded theory approach which justifies the two case studies of Paris and Cairo in the centre of the diagram. In Chapter 4, two models are proposed for urban systems and futures respectively, as well as a joint model to work with urban mobility system futures. Chapter 5 presents a set of three

methods and tools that have been developed in the context of Paris and replicated as well as extended in Cairo. The tripartite diagram reappears as pictogram throughout the dissertation to highlight the location within the dissertation. We will rotate three times through it. The first time to conceptually introduce all components and models (Chapter 4). The second time, to introduce the urban system, its futures, and the methods and tools in the context of Paris (Chapter 5.1) and the third time to replicate this process in Cairo (Chapter 5.2).

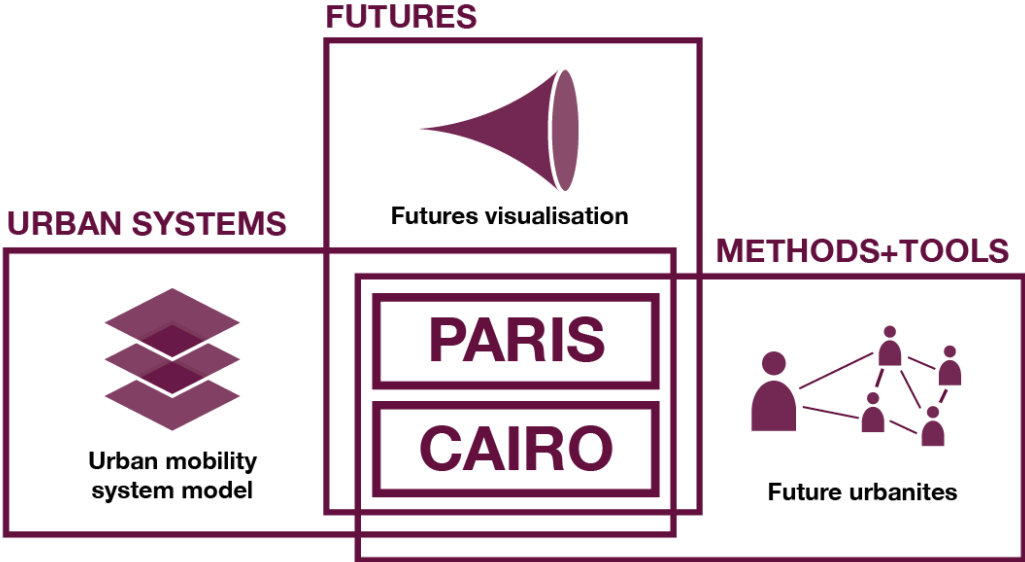


Figure 11: Diagram showing three fields of research gaps and the two case studies at their core (CC BY 4.0)

It is easy to be certain... One only has to be sufficiently vague.

Charles Sanders Peirce, 'Father of Pragmatism'

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3 RESEARCH METHODOLOGY

This chapter introduces the research paradigm, approach, and methodology, data collection methods, risks and limitations, as well as supplementary discussions of data management, ethical, and environmental concerns. The first sub-sections introduce the concerned disciplines and research paradigm including a discussion of the author’s positionality. Afterwards, the larger methodological framing is described, followed by sub-chapters on the different research methods applied throughout the dissertation, as well as the corresponding data collection and analysis methods. The chapter ends in the presentation of the project timeline, its identified risks, as well as a discussion on research ethics, open research principles, and data management. Figure 12 highlights this chapter’s contribution to the overall dissertation: building on the theoretical foundations of the literature review and constituting the methodological basis for Chapter 4 and 5.



Figure 12: Chapter 3, Research Methodology situated in dissertation structure (CC BY 4.0)

3.1 Research disciplines and paradigm

The theoretical foundation of this work origin from complex systems theory and futures studies, and to a certain degree field-specific transport and urban planning theories (Figure 13). The project’s transdisciplinarity¹² – as well as the backgrounds of the research team (i.e., design/industrial/mechanical engineering, social and behavioural sciences, architecture, and urban development studies) – necessitate a research paradigm critically combining concepts from those fields. In the following, we attempt to outline this to situate the research in the larger context.

¹² We distinguish between multidisciplinary as collaborative co-existence of disciplines, interdisciplinary as the concurrent use of different disciplinary lenses and/or methods, and transdisciplinarity as a theoretical and methodological integration leading to new methods or perspectives (cf. Lawrence, 2010).

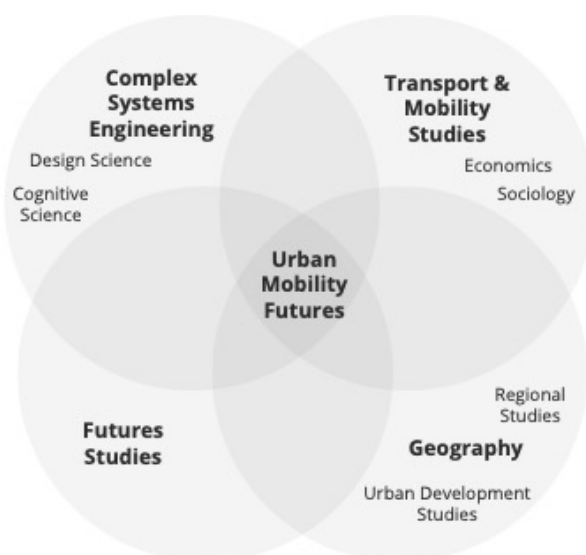


Figure 13: Four key scientific fields relevant to urban mobility futures (CC BY 4.0)

First, the ontological framing spans between *structural realism* and *bounded relativism*. The former refers to reality as being ‘described by scientific theory, but its underlying nature’ remaining uncertain (Moon and Blackman, 2014). This ontology applies to large parts of the presented research where, for example, the current primarily physical reality of an UMS can be described up to a certain degree by using adequate methods. On the other hand, bounded relativism refers to ‘mental constructions of reality [that] are equal in space and time within boundaries (e.g., cultural, moral, cognitive)’ (Moon and Blackman, 2014). This bounded relativism finds its application in several primarily societal and behavioural elements across socio-economic contexts, as well as the elements situated closer to futures studies.

Due to the introduced research fields and disciplines as well as the dominance of qualitative research and underlying uncertain futures, a predominantly pragmatist approach is applied, combining elements of post-positivist and constructivist stances (Moon and Blackman, 2014; cf. Sousa, 2010). While a positivist approach postulates that a singular objective and measurable reality exists which only requires the right tools – originating from natural sciences – a post-positivist perspective calls for the use of ‘multiple methods [...] to create a *valid* belief because all methods are inadequate’ (Moon and Blackman, 2014, p. 3, italics from source). Finally, constructivism questions the neutral and one-directional relationship of the researcher as subject and the studied phenomenon as object, instead proposing that the researcher co-constructs the reality through her activity instead. In practice, this means that we utilise the research methods identified as the most adequate for the respective research challenge – combining quantitative and qualitative research – while acknowledging simultaneously the imperfection thereof as well as the impact of disciplinary and personal characteristics on the conducted research. Building on the impact of personal characteristics, the next section outlines the researcher’s positionality.

3.2 Positionality of the researcher

Positionality ‘describes an individual’s world view and the position they adopt about a research task and its social and political context’ (Foote and Bartell, 2011; Savin-Baden and Major, 2013; Rowe, 2014, in Holmes, 2020, p. 1). A statement thereof – or

alternatively that of the author's reflexivity – becomes increasingly common in social sciences to acknowledge and disclose the researcher's influence.

We treat this in three ways: 1) The larger context, 2) A specific positional disclosure, and 3) Actions taken to mitigate any disproportional interference with the work's scientific ambition. For the former, we contextualise the research in the underlying personal motivations (Chapter 1.1) and the principal researcher's academic and professional background, as well as preceding or concurrent affiliations and activities (see Appendix AP.4, author's Curriculum Vitae). This includes active roles in networks with clear, predominantly socio-environmental goals, as well as events and fora with clear normative stance, and working outside the doctoral research on topics such as activist research in urban studies. While not considering this work an activist one, there is a clear objective behind to contribute to primarily social and environmental dimensions of sustainable development with an unavoidable influence on made research choices during the project as well as the ambition to create knowledge and contributions which find application and replication in practice after the research project.

Aside from the larger context, the author is a white, able-bodied male from a middle-class family in rural Northern Germany. While having had the opportunity to live and work in, and experience diverse global contexts, any analysis of individual and primarily socio-economic challenges – central in the urban mobility discourse – are always impacted by this lens. This applies already to a rather socially diverse and spatially unjust Parisian context but even more so to a much more economically, culturally, and linguistically distant context of Cairo. Some examples of what this means in practice are the inability to fully comprehend perceived or actual exclusion from certain spaces, e.g., due to physical impairments, financial situations restricting choices between slightly different-priced mobility options or the feeling of insecurity for female or non-binary passengers in, for example, nocturnal public transport.

This underlying normative context and individual position are foremost important to be disclosed but shall also be mitigated as far as possible. This is attempted via a triangulation of research methods and data sources, including the study of grey literature and personal reports, interviews, and local immersion, to maximise the understanding of diverse lived realities. Furthermore, quantitative approaches are applied throughout to overcome potential biases and avoid omission of relevant but non-central observations. Finally, urban mobility can be defined in various ways, but its physical manifestation remains for most people walking from one place to another or using various types of paratransit and public transport. Daily authentic experiences thereof are considered crucial and not possible to be replaced by second-hand data. Consequently, a significant part of the duration of doctoral project – as well as the prior decade – has been spent walking, running, cycling, and testing everything from electric scooters, car-sharing, and automatised shuttles to paratransit such as bicycle and motorcycle taxis, micro- and minibuses, tuk-tuks, and mass transit across many of the leading urban agglomerations in Europe, Asia, South America, and Africa. Concluding, the intention of this section was highlighting the author's position and assumed potential impact on the research. Nevertheless, the described position is not seen as a restriction – just crucial to be kept in mind – but instead even beneficial as it enables a comparative and external international perspective as well as a systemic lens.

3.3 Research methodology

Regarding the specific research methodology, the developed research design feeds on two major concepts. First, the research is conducted in the context of complex system engineering and design engineering and building on the Design Research Methodology (DRM, Blessing and Chakrabarti, 2009). Second, elements of grounded theory contribute to the methodological framing for theory building through deductive practices (McGhee et al., 2008, p. 335; Glaser and Strauss, 1967).

3.3.1 Design Research Methodology

Figure 14 shows the standard DRM framework, extended by a column on the equivalent of each stage within this work. The first step, *Research Clarification*, aims to define a specific problem. In our case, this results from the Research Chair as well as the context description and problem statement in Chapter 1, extended with the literature review in Chapter 2. The *Descriptive Study I* aims to build an understanding of the problem by using empirical data. This refers primarily to the Paris case study and the more detailed description of field-specific elements in Chapter 2. In the *Prescriptive Study*, supporting artefacts are created building on the first descriptive study. This results in the extension and validation of the theory- and interview-/workshop-based models of future UMS, as well as three methods and tools to localise scenarios and adapt people and populations to future scenarios. Finally, the *Descriptive Study II* contributes primarily to the evaluation of the models and methods which is achieved via the second case study context in Cairo. While presented as a linear approach, many iterations take place, especially between the first descriptive and the prescriptive study.

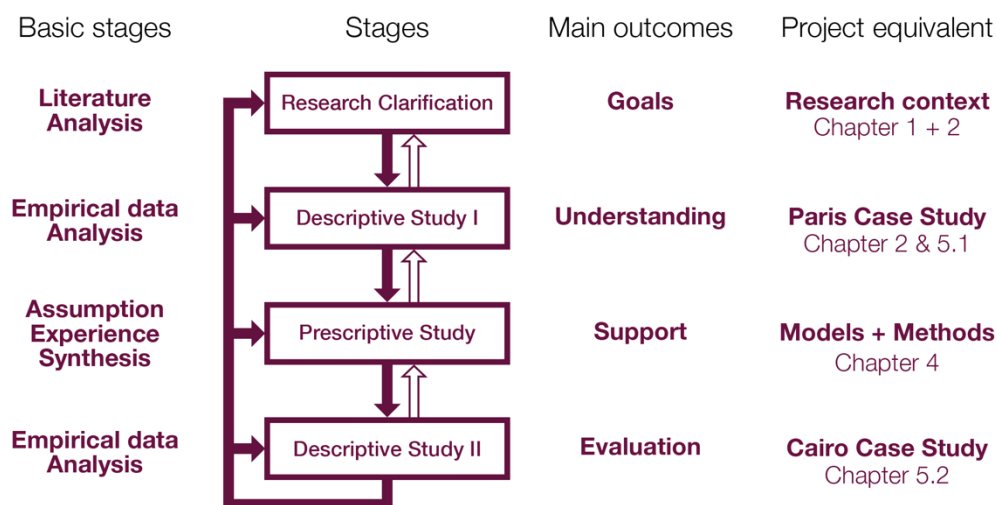


Figure 14: Design research methodology (DRM) framework (adapted from Blessing and Chakrabarti, 2009)

Regarding the research methods and tools, we apply a mixed-methods approach combining different quantitative and qualitative methods. In particular, we are triangulating conceptual elements with quantitative data and findings from field research. As a structuring element for the applied research, a case study research design has been developed. In the following, the case study research methodology as well as the different data collection methods are described.

3.3.2 Case study research

Case study research refers to an empirical research strategy from social sciences which takes one or several cases to either deduct or generalise information from them,

and/or create theory (Yin, 2003). While it has limitations resulting from the small number of studied examples, it can compensate by in-depth understanding of the cases and the ability to be applied in complex contexts. Case study approaches are recommended 'when the investigator has little control over events, and when the focus is on contemporary phenomenon within some real-life context' (Yin, 2003, p. 1).

We work with two case studies but instead of a comparative case study approach, use the first case study context of Paris to develop theory and methods while using the second of Cairo to replicate and validate them. For the case sampling strategy, we use critical case sampling (Quinn Patton, 1987). The unit of analysis is that of the respective UMS with a zoom in on specific challenges introduced later on (Yin, 2003). The timeframe is more difficult to define as the historical dimension in urban settings is challenging to clearly delineate. To provide an example, most historical urban areas still permit to identify early street layouts, covered-up streams, defence structures, or consequences of war- or disaster-related destructions and subsequent reconstruction. Thus, while the historical start is fuzzy, our focus is on the current situation (referring to the research period of 2020-2023 and data from 2015 to 2022, mostly skipping Covid-19 irregularities), as well as the future. This work focuses on 2030 as it permits a balance between data availability, uncertainty reduction, and temporal relevance for policymaking and industry.¹³

Within the case studies, a mix of explanatory, descriptive, exploratory case study methods are used. To address critiques of case study research, triangulation can be used. Quinn Patton refers to four types of triangulations: That of data sources, different evaluators, perspectives on the same data set, and of methods (Quinn Patton, 1987, in Yin, 2003, pp. 98-99). We use both triangulation of data sources and methods, in particular using primary and secondary data, interviews and surveys, as well as quasi-experiments. Quasi-experiments are alternative approaches when traditional experiments are not suitable due to no clear system boundary and control of context and phenomena within. The combination of these methods allows generalisation within constraints while always benefitting from further case studies and extended replication.

Within the two descriptive studies of the DRM framework, we use the three steps of the case study method by COSMOS Corporation (in Yin, 2030). The first phase, *Define & Design*, consists of developing theory, selecting cases, and designing a data collection protocol. The second, *Prepare, Collect, & Analyze [sic]*, refers to the iterative or, in our case, concurrent execution of the case studies and the reporting thereof. The final stage, *Analyze [sic] & Conclude*, refers to the drawing of cross-case conclusion, the modification of initial theory, the development of policy implications, and the cross-case reporting. The first phase is primarily equivalent to the next chapter. Conducting the case studies is the core of Chapter 5. Finally, the cross-case discussion and theoretical as well as practical implications, are shortly introduced at the end of Chapter 5 and further elaborated on in Chapter 6.

The two sets of overall case studies are described briefly in the following sections. As the application context is that of design, defined as the process of deliberately moving from the current situation to a preferred one, it requires foremost that the current situation is not the preferred one. Thus, additional to the overall case and introduced

¹³ Interviews resulted in frequent idea-to-market durations between 5-10 years, depending on sector and product/service complexity.

problem statement (cf. Chapter 1.3), we identified specific thematical challenges for the case studies. These are briefly introduced below, including the justification of their choice, and further detailed in the case study descriptions in sub-Chapters 5.1.1 and 5.2.1.

Case study of urban mobility in the Paris region

The first case study is that of the Paris region. While it is partially predefined by the involved institutions' locations and the focus of the research chair, it also is the second largest metropolitan area in Europe and exemplary for many challenges of large urban areas. A particular focus is on socio-spatial injustice, as well as the challenge of connecting different areas across highly heterogenous metropolitan areas, including highly dense urban centres and disconnected peripheral areas which are increasingly being integrating into the urban fabric but unsuitable – at least temporarily – for traditional mass transit.

Case of urban mobility in the Cairo region

The second case study is that of greater Cairo. It constitutes another of the largest, in this case global, metropolitan areas, with continuing urbanisation, even higher challenges of socio-spatial injustice and similar issues to integrate new peripheral developments in the existing urban fabric and connecting them via sustainable mobility options. The choice for Cairo origins of these shared characteristics, as well as it being home to different modes of paratransit not present in Paris, limited existing research and data, and stronger levels of uncertainty, matched by a high level of local expertise and well established research institutions permitting to access expertise. Furthermore, Cairo is a leading global city which shares characteristics with many other urban areas in the Global South which in few years will be home to most of humankind – and consequently origin of emissions, pollution, and other mobility-related effects.

3.4 Data collection

To be able to conduct the case studies, a large amount of data is collected. This serves primarily to study current UMSs and their components, developments towards the future and transitions, and the accompanying design processes (e.g., involved stakeholders, concerned territories, used artefacts and processes). The diversity of studied data also contributes to the triangulation of data to solidify the research approach (Yin, 2003). The following sections briefly introduce each used data collection and analysis approach.

3.4.1 Literature review and content analysis

The first and most common approach is that of literature review and content analysis. The literature review was conducted following different principles. Foremost, literature known by the research team and therein referenced are used, complemented with targeted searches. In some cases, grey literature is used to supplement academic literature when data gaps are identified. Elements of systematic literature review via the Web of Science and Google Scholar are used throughout to ensure that no key literature on specific topics is missed (Grant et al., 2009). Content analysis is conducted for public policies and other documents that supported the case study description.

3.4.2 Field observation

The second research strategy is that of field or participant observation. While initially limited by the Covid-19 pandemic, the regular and ongoing use and observation of mobility services and solutions is considered crucial for the understanding of UMSs, modes, and use cases. This includes a wide use of modes of mobility, as well as the exploration of different geographical areas and different times during the day. While already important in Paris, this part has been fundamental in Cairo to – even if always limited – try to grasp in a limited time as much as possible how different people in different areas move from A to B, and what challenges are related to it, e.g., the identification of the correct buses, unreliability regarding schedules, or risky situations due to unplanned stops or informal bus-stops.

3.4.3 Interviews

16 semi-structured expert interviews lasting between 50 minutes and 1:15 hours with open-ended questions are conducted for the Paris case. They serve primarily the UMS and component definition. In Cairo, 20 unstructured expert interviews between 30 minutes and two hours are conducted, mostly serving to support the understanding of the socio-spatial context. The selection of interviewees is done via purposive sampling, making use of participatory stakeholder mapping, starting with key actors, open sampling through social media, and snowball sampling after the aforementioned. The interview guidelines for the semi-structured interviews in Paris are provided in Annex An.2. The outreach to experts in France is made in French, with the proposition for English interviews after initial exchange and confirmation for easier post-processing. All interviews are fully transcribed, in the case of interviews conducted in German or French, translated to English and coded using the software Atlas.ti. Due to the research's focus on past, present, and future, interviews are structured into separate sections referring to different time periods. For this, the order of present, past, and then future is used, following recommendations by Quinn Patton (1987). Within the temporal sections, simple descriptive questions initiated the interviews, followed by opinions, and completed by few background questions (Quinn Patton, 1987).

3.4.4 Participatory workshops

A significant part of the PhD project is conducted in collaboration with experts from different disciplines or specific geographic contexts. For this, eleven workshops are conducted, listed in Table 1. Each of them serves different purposes and are adapted to the context and audience. In the beginning, explorative workshops dominated, focusing on testing methods and intermediary design objects. Next, workshops focused on modelling and validating created models. Finally, case-study-specific workshops followed, complemented by validation workshops for parts of the resulting tools and methods. The workshops and other data collection activities are described in Annex AN.3 and their findings used throughout the dissertation.

Table 1: List of conducted workshops and other data collection activities

Annex	Title	Period	Location	Duration	Audience
AN.3.1	Workshop on explorative future mobility situations	May 2021	Online	1:30h	Public, mixed (n=7)
AN.3.2	Interviews on partner expectations towards futures studies	Spring 2021	Online	0:30-1:10h	Chair partners (n=5)
AN.3.3	Workshop on spatialising urban mobility futures	Nov. 2021	Doha	1:30h	Urban planners (n=10)
AN.3.4	Workshop on modelling urban mobility systems	Dec. 2021	Gif-sur-Yvette	1:30h	Chair (n=5)
AN.3.5	Workshop on assessing future scenarios	March 2022	Gif-sur-Yvette	2h	Experts (n=7)
AN.3.6	Workshop on urban mobility scenarios of CPS	April 2022	Gif-sur-Yvette	1:30h	Chair partners (n=9)
AN.3.7	Workshop on enabling urban transitions	May 2022	Orsay	4 days	Experts (n=10)
AN.3.8	Interviews of urban mobility experts	Spring 2022	Mixed	0:50 - 1:15h	Experts, mixed (n=16)
AN.3.9	Expert scenario-localisation workshop in Cairo	October 2022	Cairo	2:00h	Local experts (n=14)
AN.3.10	Chair workshop on scenario simulations	June 2023	Gif-sur-Yvette	1:30h	Chair partners (n=9)
AN.3.11	Two validation workshops for decision support tool	July 2023	Gif-sur-Yvette	2*1:00h	Mixed, researchers (n=10)

3.4.5 Questionnaires

Finally, five small-scale questionnaires are conducted. These do not aim to create statistically significant samples but instead collect primarily expert knowledge. An early questionnaire, distributed during online and offline events, focused on supporting the description of research context and needs. For the second case study in Cairo, a questionnaire is used to support data collection via workshops and increase the number of participants. Finally, questionnaires are used to collect feedback from validation activities. Each questionnaire is structured in the same way and consists of a short section on background information, followed by questions with possible responses on a Likert scale as well as few open-ended questions. As the questions are predominantly knowledge and opinion-focused, linear scales usually contain an even number of possible responses to avoid the selection of the central one (cf. Quinn Patton, 1987).

3.5 Research validation

Aside from the data collection, a short methodological discussion is dedicated to validation activities. Validation is an important element of DRM as it shall ensure that the proposed methods and tools are both utile and adequate (Blessing and Chakrabarti, 2009). This work uses validation on three levels. Generally, most qualitative methods, mostly prospective ones from the futures field, have always inherent challenges of validation as one cannot wait for a decade to verify if the assumptions are sufficiently accurate. Further, existing research is limited due to changing institutional contexts and difficulties of data access (Goodspeed, 2020). To mitigate this limitation, we build on existing methods for components of the proposed work to ensure as far as possible that valid and useful methods and assumptions are integrated.

Secondly, we make use of different expert-based validation processes, e.g., via co-creative workshops, interviews, as well as various conference and internal presentations and subsequent discussions. The involved stakeholders include public and private ones who are partners of the Anthropolis Chair. Further, within both geographical contexts, a network of local urban development and mobility experts provides in-depth insights on the UMS, their functions and challenges, as well as feedback on the proposed models, permitting a continuous validation of partial outcomes.

Finally, we do not claim that all propositions and results presented in this work are correct. Instead, we propose primarily methodological frameworks or tools which are modifiable and wherever possible reproducible by using open data, open-source software, and providing commented source code where applicable.

This in combination should permit a partial validation wherever possible. More detailed descriptions of these activities are embedded in the subsequent chapters. In conclusion, the major challenge of validation remains that of futures. We argue that the considerate, data-driven, and expert-based creation of multiple futures is not automatically 'valid' but has a higher probability to cover the future UMSs due to the set of scenarios, indirectly contributing to the validity of methods and tools to which the method is applied.

3.6 Project timeline

PhD projects in France are usually limited to three years. Figure 15 shows the rough timeline of activities within this timeframe. In the first half of the first year, literature review and research into theories, concepts, and terminology prevailed. The second half extended this review by methods, tools, and a first perspective on the UMS of the Île-de-France (IDF) region. After a bit less than half of the time, a detailed research plan was created which has been mostly followed thereafter. This includes a strong focus on the first case study during the second year, the work on the second case study in the first half of the third year, and the finalisation in the last months. Both case studies are made up of parallel activities including observations, workshops, and interviews, within limitations surveys, and concluded by analysis and reporting.

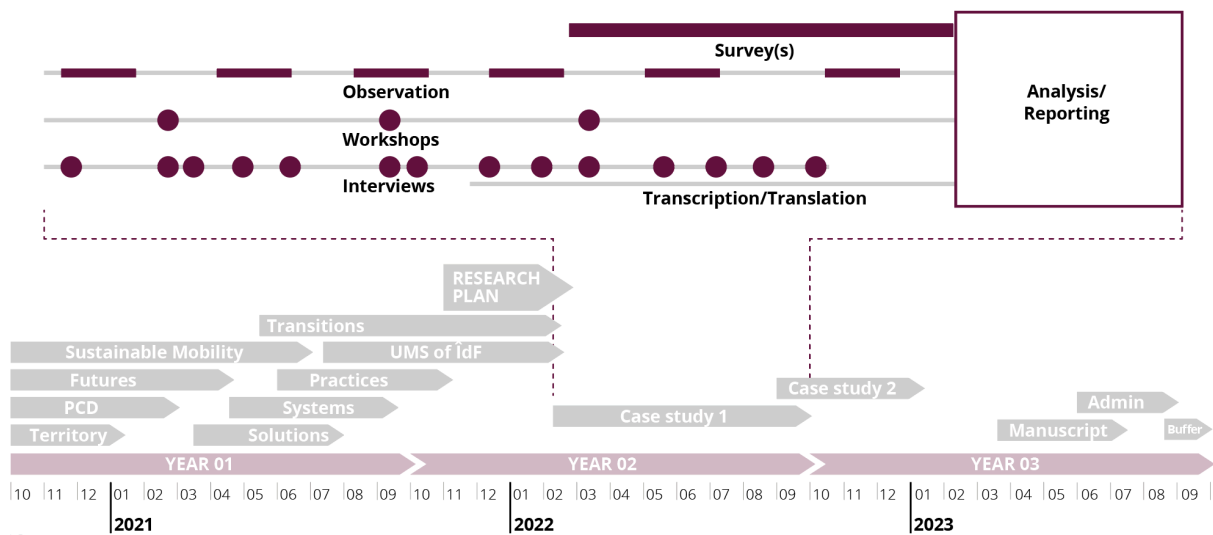


Figure 15: Timeline of activities created in February 2022 (elements are indicative of actual timing; CC BY 4.0)

3.7 Risks and limitations

From the point of the creation of the research plan onwards, a risk registry has been created to be prepared for potential project uncertainty, mostly regarding data collection and the case study work. These are listed in the next section. Furthermore, limitations have been identified to delineate where the limits of both the research process and the potential or realistic contributions are. These are described in the second section of this sub-chapter.

3.7.1 Risks and mitigation planning

This project started a few weeks before the second wave of Covid-19 in France, putting a significant and anticipated strain on effective collaboration, stakeholder outreach, and overall participation in scientific exchange. Therefore, the risk registry (Table 2) has been initially compiled in the first year and is reviewed and extended throughout the doctoral research project.

Table 2: Research project risk compilation and mitigation responses

Risk	Response	Likelihood
Further Covid-19 consequences restricting observations in realistic conditions	Interviews and (grey) literature focusing on pre-Covid-19 situation to ensure reliability.	***
Further Covid-19 consequences restricting access/availability to expert interviews	Focus on local experts, with possibility to conduct all interviews online, even if in-person interviews are favoured.	**
Difficulty to reach enough interviewees	Starting with the immediate professional network of the home institutions, a basis is ensured. Further expansion shall be ensured through various means of outreach (incl. by word of mouth, mailing lists/professional online platforms, and snowball sampling).	*
Restricted possibility to collect data and validate research from local project partners	Collaborate with different stakeholders and experts, including outside the Chair's context. Focus on quantitative and desk-based approaches where co-creative activities are restricted.	***

Risk	Response	Likelihood
International travel restrictions intervening with second case study project	An international focus can be adapted to a second European case study to anticipate possible restrictions. In case of further limitations, a second French case study (e.g., metropolitan area of Lyon) can be considered.	*
Research on social subjects like urban mobility can touch on political topics which in some countries may bear risks.	A balance between objective research and responsible actions is sought, extended by a diplomatic approach to communication and the awareness that some non-central topics might be dropped or deprioritised for external reasons. Local expertise shall assist in the navigation thereof.	**

3.7.2 Limitations

Additional to abovementioned risks, a number of limitations are identified which are either inherent to the field of research or otherwise unavoidable. The first is the coincidence with the Covid-19 pandemic, resulting in limitations of foremost primary data collection in the first half of the doctoral project. Additionally, the author is fluent in German and English but learned French during the project and has only notions of Arabic. A resulting limitation is the potential loss of information and interactions in French in the first year. However, from the beginning, interviewees and workshop participants are given the chance to respond in either French or English, attempting to limit the negative impact as much as possible. Further, the research operates in a context of complexity and wicked problems (cf. Chapter 1.2.2). The complexity results in a high likelihood that some information is always missing while the wickedness of the problems adds a level of diverse and biased stakeholder perceptions, necessarily reflected in interviews, workshops, as well as literature.

Regarding the case study research method, every case is different, resulting in limitations for generalisation. This was attempted to be mitigated via a careful choice and complementarity of the case studies. Lastly, the doctoral project is conducted in three years with contributions to other ongoing works and significant parts spent on theoretical research. This limits field work to short periods which are seen as crucial, yet require a focussed, possibly too narrow perspective in some instances. Finally, a more participatory co-creation process throughout all stages of the research, mostly with civil society is considered to potentially benefit the research output quality but is excluded for multiple reasons from the scope of this project. Instead, civil society inputs are considered only via secondary data.

3.8 Research ethics and data management

This section outlines ethical concerns, primarily regarding data collection, analysis, and dissemination. Furthermore, it outlines the underlying data management and open research principles.

3.8.1 Research ethics

Human research subjects: The research project conducts interviews, surveys, and workshops with human participants representing professional actors. Their diversity is considered in sampling, aggregation, and pseudo-anonymisation where possible. Persons without ability to ensure informed consent (e.g., children, people with non-physical disabilities) are not considered as subjects for the study.

For each research subject, an informed consent form (see Annex AN.1) is produced in an adequate language and in case of in-person interviews signed and handed out in copy or in case of virtual interviews distributed in advance or in the beginning of the interview with a recorded response confirmed/negating the form's content in part or full.

Personal Data Collection/Processing: Data is only collected when and where needed directly for the research study. It is not used for other purposes than those stated without sound justification and prior anonymisation of all personal and attributable data. Master recordings of transcribed interviews are encrypted and stored only for later research validation purposes but never for other uses or distribution in any kind.

Security measures: All analogue data are kept in protected areas only accessible to people working on the research project. Non-anonymised master files are archived. Digital data is only accessible through password-locked and adequately protected computers. Digital non-anonymised master files (such as interview recordings) are additionally encrypted. Despite their protection, they are kept ensuring the validation of research process and outcomes. Contact and other personal information of research participants are saved in separate password-protected files.

Any processing, data storage, and transcription software used is GDPR compatible. Prior to the start of data collection procedures, adequate training in data privacy, research ethics and open research principles has been conducted.

Pseudonymisation and anonymisation techniques: For interviews and other primarily qualitative data, names, and position, as well as other personal information, are pseudonymised as long as no written informed consent has been given stating the opposite. A separate, password-protected file is kept which links the pseudonyms with the original data, only accessible by the team of researchers.

3.8.2 Data management

This section describes the principles of data collection, storage, sharing, and preservation after the completion of the doctoral research project. Therefore, we distinguish between analogue and digital data, as well as master files, safety copies, attribution files, and working files.

For analogue files, the original master files are kept in an unchanged form and kept in a secure location in the office space of the research institution. For further analogue treatment, they are – if necessary – pseudo-anonymised and copied. In the moment in which they are digitised, they are treated further as digital data.

Digital data's treatment is divided in the different document types. Master copies (e.g., original survey outcome exports) are kept in an unaltered, protected archive. A copy thereof is – if needed – pseudo-anonymised and can thereafter be used for further data visualisation, analysis, or distribution. From files of each step (master copy, pseudo-anonymised copy, and working files), automatic and regular safety copies are made to ensure the avoidance of data loss. All data processing steps are documented in detail to enable full traceability.

Following the completion of the doctoral project, the data is stored digitally encrypted, and analogue in protected archives. Non-used data or copies may be destroyed, while other files are archived for ten years except in cases in which other requirements are stipulated by involved institutions or law.

3.8.3 Open research

The research project follows the suggestions stipulated in EU Directive 2019/1024¹⁴ and the second national plan for open research in France¹⁵. This means that all key research publications are made available under at least green open access through the availability of either pre-prints in publicly accessible repositories and/or gold open access publication. In some cases, embargo periods must be respected, partially circumvented by systematically providing file versions on request via the French research repository HAL and ResearchGate. Most visual materials in this dissertation are marked with the Creative Commons license **CC BY 4.0**, allowing the reuse for distribution, remixing, adaptation, and building upon as long as attributed accordingly. Wherever possible, open data was used, and the source code was made available for full replication. This information is provided in a dedicated box at the beginning of each concerned section.

All collected data is accessible on request under the precondition that the above-outline ethics considerations are respected. After the completion of the doctoral project, the data is preserved by IRT SystemX and CentraleSupélec. The research logs and process descriptions (including audio recordings, original language transcripts) are conserved and can be requested (within the ethical restrictions) for a duration of ten years after the completion of the doctoral project for purposes of further research or verification purposes if not otherwise requested by individual subjects or legal requirements.

3.8.4 Environmental impact of research

This work's objective is contributing to sustainable urban development. The process of analysing the topic and interacting with the research community requires a certain degree of mobility of the researcher, additional to energy use resulting from digital infrastructure. Where possible, trains and busses were prioritised over planes. The remaining CO₂ emissions associated to the following emission fields and the three years of PhD research at the Anthropolis Chair result from on average three days per week commuting two times 25 km by public transport, travel to conferences by respective mode, operating a computer for about 6500 hours, and keeping about 100 GB of files in cloud storage. This adds up to about 4.263 tons CO₂ for flights, 280 kg to produce the personal computer purchased for the PhD project, 195 kg for commuting, 35 kg for its use, 11 kg for trains, and 0.6 kg for cloud storage. Or 4,785 kg CO₂ in total. While only a rough estimate, it provides an overview of the environmental impact and permits its partial mitigation. Flights have been offset throughout and the remaining 522 kg have been offset at the end of the project.¹⁶

¹⁴ <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A32019L1024> [accessed 06 August 2023]

¹⁵ Deuxième Plan National pour la Science Ouvert, <https://www.ouvrirlascience.fr/deuxieme-plan-national-pour-la-science-ouverte/> [accessed 06 August 2023]

¹⁶ The author is aware of limitations of CO₂ offsetting but sees it as an alternative for emissions that are difficult to be avoided or already emitted. The German service Atmosfair (www.atmosfair.de/en/offset/) has been used as a transparent as well as externally controlled and monitored service provider.

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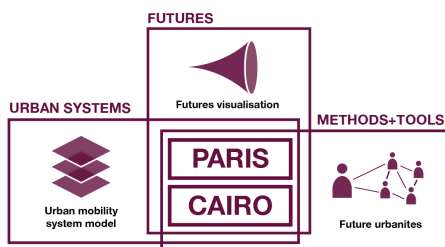
There are no separate systems. The world is a continuum. Where to draw a boundary around the system depends on the purpose of the discussion.

Donella Meadows, Systems Scientist

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4 DESIGN FRAMEWORK: MODELLING FUTURE URBAN SYSTEMS

Research question	How to model future urban mobility systems and urbanites?
Methodology	Mixed-methods, qualitative research incl. literature review, interviews, workshops, and surveys.
Results	This chapter results in a set of three models which have been developed in the context of Paris and describe the interactions between system components. Furthermore, a range of approaches to model users and people is introduced and results in a joint representation.
Contributions	<p>a) Urban mobility system model. b) Model and visualisation for future scenarios via futures cone. c) Integrated urbanite model for people-centred design.</p> <p>On the theoretical side, the contributions are two-fold. The urban mobility system model does not largely differ from existing models but adds a directional and ordered relationship between its components which permit its dynamic modelling without endless feedback loops. It thus presents a functional abstraction of a complex system model. Secondly, the definition and conceptual modelling of people-centred design and its consideration across time and space permits a clearer distinction between existing design frameworks and a structured comparison between design methods and their objectives.</p> <p>For practice, the contributions act primarily as support models which can enable to easier conceptualise or visualise, for example, futures. The utility of the revised and structured futures cone visualisation has been widely proven through use cases in workshops, training, and uptake in the scientific urban practitioners' community.</p>
Implications	



This chapter is the first of two core chapters of this work. Extending the theoretical discussion started in the literature review, it aims to provide a conceptual and methodological framework to design future urban mobility. As shown in Figure 16, Chapter 4 builds on the literature review and previously introduced research methodology and

prepares for Chapter 5. The chapter is organised in three sub-sections.

First, we propose a *systems thinking approach to model urban mobility* as complex system, constituted of three layers: People, infrastructures, and people. The description is kept short and only on key concepts and elements reused thereafter. A more detailed description of the underlying approach can be found in a dedicated conference paper (Appendix AP.3.1).

Building on the system model, the second sub-chapter focuses on the futures dimension. Using theory and concepts from the field of futures studies introduced in Chapter 2.2, we first propose a *revised futures cone as conceptual representation* and simultaneous intermediary design object for participatory design activities. The system model of urban mobility combined with the futures dimension leads to a conceptual model that permits to work strategically with urban mobility futures, especially using scenarios. The third and final sub-chapter zooms in one of the three system layer – people – and introduces its elements and characteristics, a way of modelling it, and the integration in design processes, exemplary shown for persona-

based methods and agent-based mobility simulations. Each of the contributions of this chapter are applied and tested in the subsequent chapter.

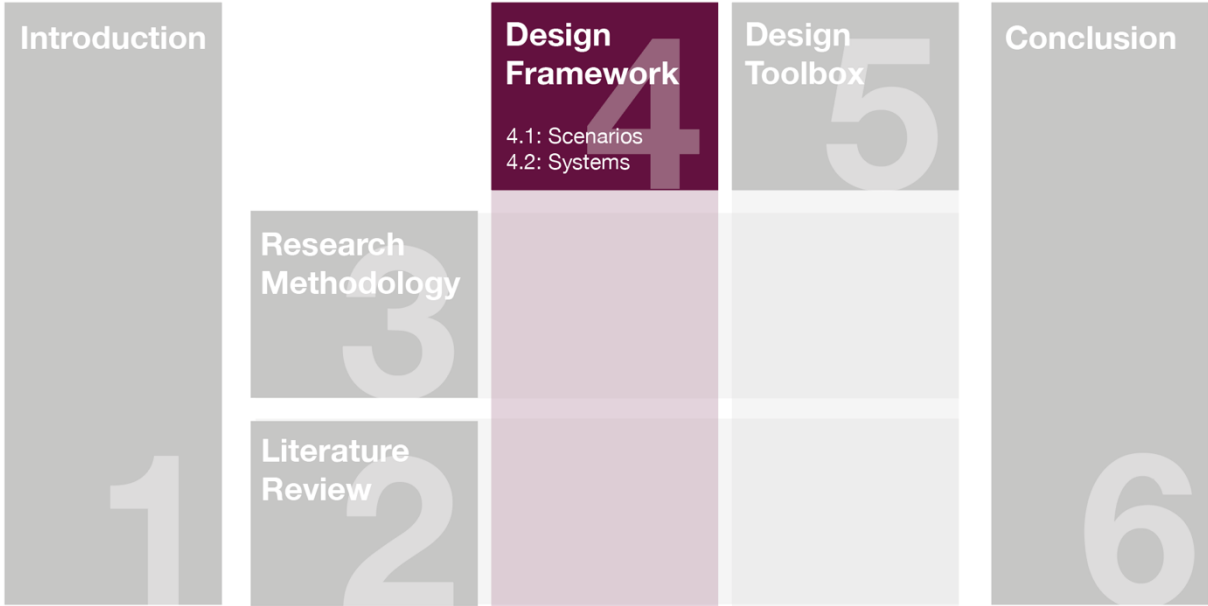
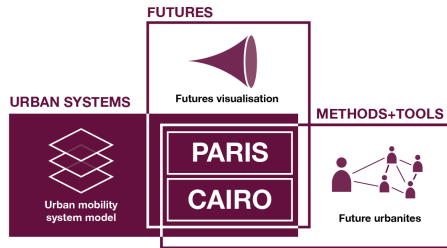


Figure 16: Location of Chapter 4 on the design framework in overall dissertation (CC BY 4.0)

4.1 Modelling urban mobility systems and their transitions

Research question	How to model urban mobility systems?
Methodology	Mixed-methods, qualitative research incl. literature review, interviews, workshops, and surveys.
Results	This section results in a model which have been developed in the context of Paris and describes the interactions between system components.
Contributions	a) Urban mobility system model.
Implications	The urban mobility system model does not largely differ from existing models but adds a directional and ordered relationship between its components which permit its dynamic modelling without endless feedback loops. It thus presents a functional abstraction of a complex system model.
Reference articles	Gall, T., Vallet, F., Douzou, S. and Yannou, B. (2021) Anticipate, Adjust, Adapt: Managing Sustainability Transitions through multiple Scenarios of Urban Mobility Futures. 49th European Transport Conference, online, Sept. 2021. Gall, T., Vallet, F., and Yannou. B. (2022) How to visualise futures studies concepts: Revision of the futures cone. Futures, 143/103024. https://doi.org/10.1016/j.futures.2022.103024



In this sub-chapter, we attempt to provide a conceptual and structured foundation for the systemic work on urban mobility to inform the modelling of UMS and their futures. To do so, we make use of *heuristic models* that allow us to reduce the real-world complexity to a manageable degree while still understanding the elements, its

interrelations, among many others. We apply a *systems thinking* perspective, integrating its complex dimension to account for urban mobility’s inherent complexity and behaviours, and the *socio-technical* perspective to enable an integrated view on social components such as behaviours and practices, as well as technical elements, such as new innovations, digitalisation of the transport sector, among others.

This chapter introduces the field of complex systems, their application in the urban context, and their theories, concepts, and relevance for this work. They are presented here instead of in the literature review as they immediately inform the modelling of UMSs in general and that of Paris as a case study. We start with a short historical introduction of complexity across related fields and thereafter describe key concepts deemed relevant for the modelling of urban mobility. Next, we apply it exemplary to different scales, namely (1) an urban area as a system-of-systems (SoS) and (2) the urban mobility system (UMS) as a complex adaptive socio-technical system. The latter is complemented by interviews and workshops, conducted in the context of Paris.

We start with a brief introduction on complex systems. A *simple system* has a clear structure, purpose, etc. For example, a bicycle. It has a system architecture (e.g., frame, wheels), a couple of components (e.g., chain, pedals, bell), a purpose (i.e., moving a human from A to B with physical power). But there is nothing complicated or complex about it. Next, we can look at a *complicated system*. For example, a modern hybrid car. It has multiple sub-systems (software, mechanics, engines, ...) with multiple and increasingly frequent interactions. Many things are happening simultaneously that most people are neither able to repair nor understand the system in its totality. Then, there are *complex systems*. While the concept has found application in a variety of fields, we focus here on the urban context and the application therein (cf. Forrester, 1969; Le Moigne, 1990). One of the most impactful and known urbanists of the past century, Jane Jacobs, was the first who questioned the modernist, rational, pragmatist, utilitarian, and post-war ways of planning cities which started with the Garden City by Ebenezer Howard just before the 19th century and prevailed since, advocated by Le Corbusier and many others. Missing the social dimension of urban areas, Jacobs understood urban areas differently:

‘Cities present situations in which a half-dozen or even several dozen quantities are all varying simultaneously and in subtly interconnected ways. Cities, again like the life sciences, do not exhibit one problem in organized complexity, which if understood explains all. They can be analyzed [sic] into many such problems or segments which, as in the case of the life sciences, are also related with one another. The variables are many, but they are not helter-skelter; they are interrelated into an organic whole.’

‘...theorists of conventional modern city planning have consistently mistaken cities as problems of simplicity and of disorganized [sic] complexity, and have tried to analyze [sic] and treat them thus.’ (Jacobs, 1961)

Many others have continued this line of thinking since. Jay Forrester has roughly at the same time started to apply dynamic systems modelling to the urban context (Forrester, 1969). While fully quantitative and still explorative at that stage, the same idea of urban areas as complex systems with multiple social, economic, and technological components dominates. The concept of complexity and that of complex systems has found ample application in urban areas in the past decades, mostly due to the work of Michael Batty who published his PhD titled ‘Pseudo-dynamic Urban Models’ in 1984 and has worked on it since. A recent quote summarizes his perspective:

‘In fact, although the systems approach propelled the field of urban studies and planning towards a deeper understanding of the form of cities and their liveability, the approach was found wanting in many ways. During the rest of the century, what became clear was that cities were complex systems that defy understanding, and are very different from our knowledge in the physical sciences.’ (Batty, 2022, p. 40)

Complex system architecture

With the above as larger context, we can zoom in on complex systems and different frameworks to model them. We start with the complex system architecture model introduced by Le Moigne (1990) which has since been applied to various fields (cf. Schindler, 2009). It refers to the system and its relation to four elements, namely its (1) environment, (2) structure, (3) transformation, and (4) purpose. Le Moigne describes these as the axes of the model. The environment/ontological axis refers to the structure and the system architecture itself. The functional axis focuses on activities and processes of the system, related to the functional architecture of the system. The genetic axis focuses on the evolution, life cycle, transformation and transition of a system. Finally, the teleological axis describes the purpose of the system in the context of its environment.

Figure 17 shows on the left a visualisation of the translated original (Le Moigne, 1990, p. 40) and on the right an adapted version. While the adapted version maintains the same elements and idea, a few changes were made. The system is contextualised in the environment, visualising an overall exchange between the system and its environment. Transformations are renamed/translated to evolutions, describing any type of changes of the system through internal or external causes. This has been done to clearly distinguish between transformations, transitions, and evolutions.

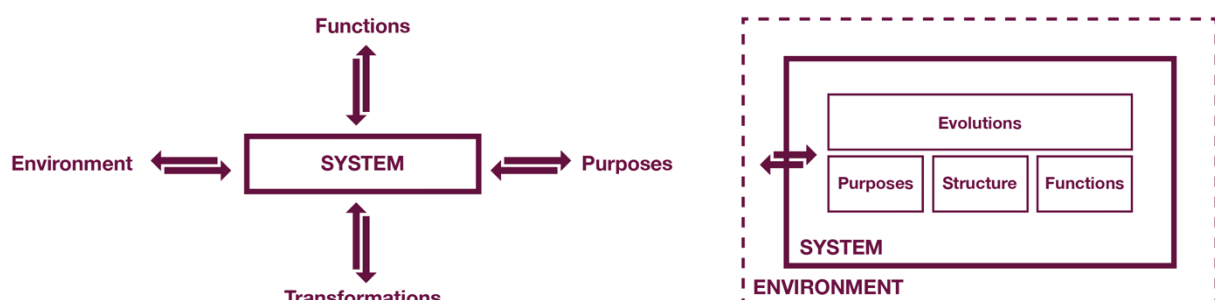


Figure 17: Complex system architecture (left: model of Le Moigne, 1990, right: adapted model)

Urban areas as system of systems

If we take the urban mobility system (UMS) as one such system, it interacts in many ways with other systems, such as the local energy system or the housing market. But simultaneously, it interacts with other systems which are either conceptually distant (e.g., technological innovation) or geographically (e.g., and urban mobility system elsewhere that might impact the system by being a forerunner of a promising technology). The latter can be traced for most of the history of Paris' 19th and 20th century between Paris and London: A mix between copying, inspiration, and rivalry. This co-existence of urban systems has been further elaborated on by Hölischer and Frantzeskaki (2021). Applying the structure of Le Moigne, we can conceptualise this as a geographical co-existence of multiple systems in the same environment (Figure 18)

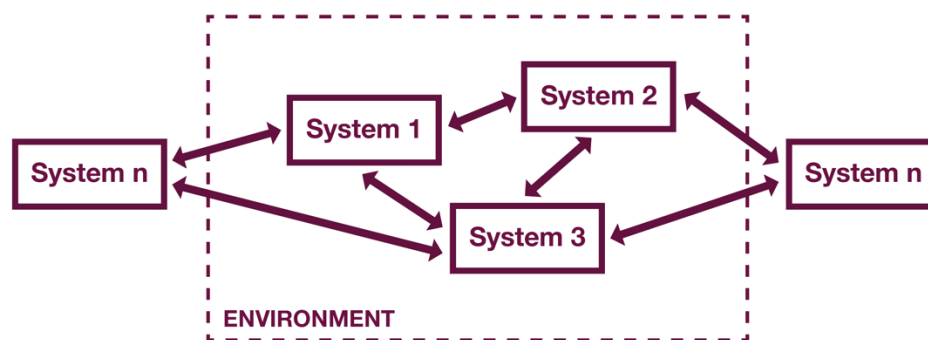


Figure 18: System-of-systems visualisation (CC BY 4.0)

Nested complexity

Taking back the introductory quote of this chapter: 'There are no separate systems. The world is a continuum. Where to draw a boundary around the system depends on the purpose of the discussion' (Meadows, 1999). Consequentially, defining the boundaries of a system is highly important but challenging. This can be attempted at different levels. If we define urban mobility as a system within the urban context of system of systems, we can zoom further in. What happens within one complex system? In the context of urban mobility systems, we can for example, zoom in on thematical sub-systems (e.g., public transport system) or also geographical sub-systems (e.g., a district or area such as the Plateau Paris-Saclay, one of the study areas of this work). The sub-systems are not necessarily complex but can be complicated or even simple systems. Within this work, we maintain an urban scale even if focusing on geographical sub-areas thereof.

Modelling Urban Mobility Systems (UMS)

With the above as theoretical framing and remembering the understanding of urban mobility as the ability to move around and access urban opportunity (e.g., jobs, education) (cf. Bertraud, 2018), the underlying system is the manifestation of everything that directly or indirectly affects this urban mobility. Transport(ation) on the other hand, refers to the actual moving of people (and goods in other contexts) and transport system referring to the physical (and increasingly digital) infrastructures behind. In a geographic urban context, the localisation of UMS balances between defining a system boundary between a closed dynamics system and outside people, goods, ideas and technologies flowing in and out. Forrester, the pioneer of dynamic system modelling, defines urban areas as closed systems where everything which is on the outside might affect the inside but where the inside does not significantly affect the outside (Forrester, 1969, p. 18). Following a similarly systematic but more

economic perspective, Bertraud (2018) defines urban areas as ‘primarily large labor [sic] and consumer markets [which] work best when the possibility of contact increases between workers and firms, among firms themselves, and between consumers and commercial and cultural amenities.’ In this context, he defines the term mobility as the ability to multiply these contacts with a minimum of time and friction.’ (Bertraud, 2018, Ch. 5).

The so far outlined theoretical assumptions act as inputs for internal workshops and 16 expert interviews aiming to identify components and interrelations of system components across temporal scales (see Annex AN.3.6 for details on the data collection). Building on these (Figure 19), we created a UMS model which contains three layers: *People*, *infrastructures*, and *services*. Despite multiple connections between the layers, we propose a logical temporal transition structure in the same order as listed above. People are the first layer as result of attraction to one area over another, primarily for job or education or other reasons (e.g., strategic governmental design interventions), increasing wealth and thus higher demand on space, decreasing transport costs or improved speed (Bertraud 2018). Next, the location of people defines the creation of infrastructure, including buildings, roads, and public transport infrastructure. The last layer, service, is the connecting layer between the two, linking existing infrastructure with the actual mobility needs of the people. The temporal structure can be applied both to working with them starting with people, continuing with infrastructures, and finalising with services. Secondly, they are also assumed to – in usual contexts – to arise in that order. First, people’s locations and needs change with a relative long-term stability, followed by the adaptation of infrastructure and the service offer which can change in some cases near-instantly. This logic of the UMS is the core element for the intended localisation and adaptation of scenarios described in the following section. The structured visualisation of the UMS is proposed together with the futures dimension at the end of the next sub-chapter.

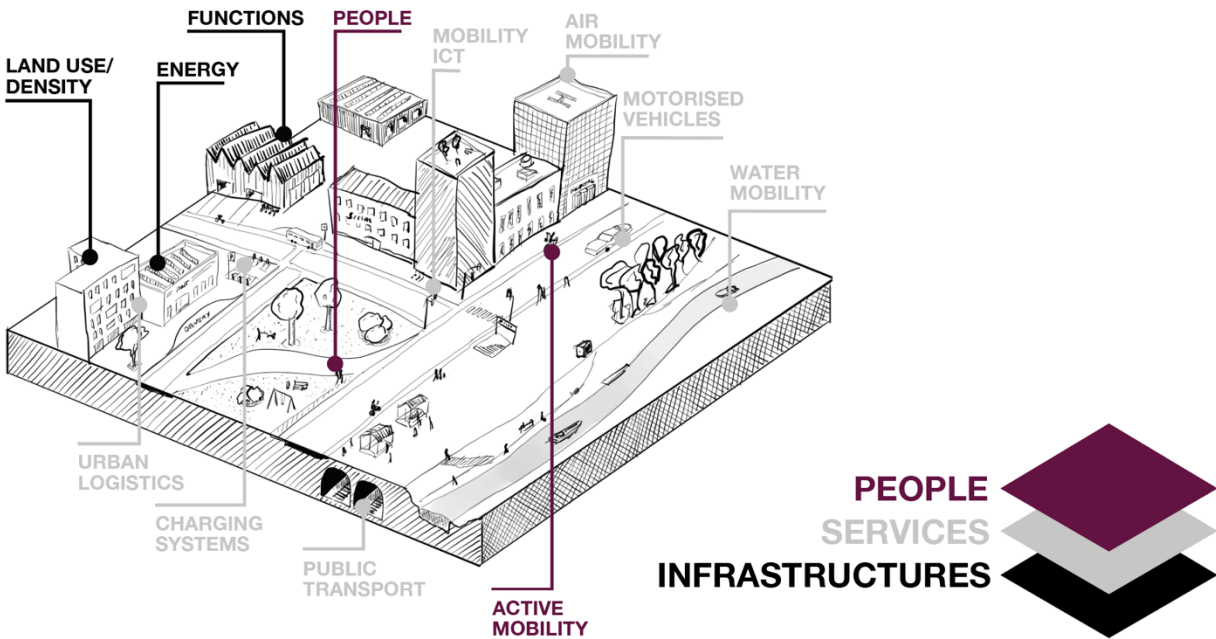
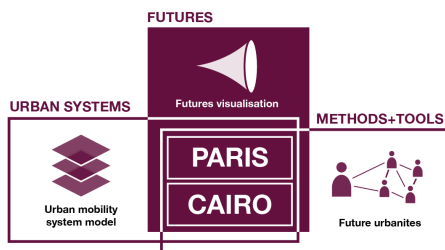


Figure 19: Visualisation of UMS and its components (CC BY 4.0)

4.2 Modelling futures

Research question	How to model future urban mobility systems?
Methodology	Mixed-methods, qualitative research incl. literature review, interviews, workshops, and surveys.
Results	This section results in a conceptual model of urban mobility system futures and their transitions.
Contributions	b) Model and visualisation for future scenarios via futures cone. This contribution act primarily as support model which can enable to easier conceptualise or visualise, for example, futures. The utility of the revised and structured futures cone visualisation has been widely proven through use cases in workshops, training, and uptake in the scientific urban practitioners' community.
Implications	
Reference articles	Gall, T. (2021) Working with multiple Scenarios: Revising the Futures Cone. Conference paper, AESOP YA Conference 2021 in Tirana, Albania, March 2021. Gall, T., Vallet, F., and Yannou. B. (2022) How to visualise futures studies concepts: Revision of the futures cone. <i>Futures</i> , 143/103024. https://doi.org/10.1016/j.futures.2022.103024



Following the modelling of UMS at one point of time, as well as their transitions, this section aims to model and visualise futures studies concepts, building on the gap of *an updated representation of theoretical futures concepts as well as future scenarios*.

4.2.1 Futures cone

This model visualisation shall serve both the conceptual framing of the proposed methodological framework of this work, as well as the discussion of futures concepts in participatory activities. The earlier introduced futures cone (cf. Figure 7, Chapter 2.2) has found the most widespread application to communicate some ideas, such as a widening possibility space over time or various levels of plausibility. It is also referred to Cone of Plausibility(ies) or Cone of Possibility(ies) with the same meaning, or confusingly Cone of uncertainty (Figure 20) which, however, represents the decreasing level of remaining uncertainty as closer one moves towards a future timeframe, commonly used in project management.

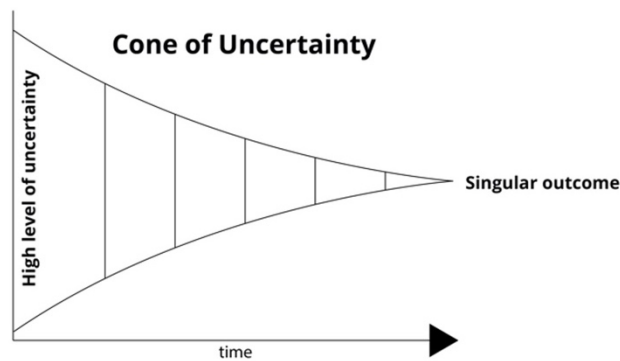


Figure 20: Cone of uncertainty (based on Bauman, 1958, in Gall et al., 2022)

Using the futures cone as visualisation does not originate from its ability to represent every element of futures studies. For example, the cone has been criticised for its linearity or various abstractions as outlined further below. Nevertheless, it remains to be used widely and appears as the least inadequate mental model to communicate multiple futures (Voros, 2017; Candy, 2010).

The first version of the 'cone of plausibility' was most likely developed in late 1986 within the US Department of Defense by a group of researchers and personnel and published by Taylor first in 1990 and a revised version in 1993 (Taylor, 1993). Another early cone is commonly attributed to Hancock and Bezold (1994), which closely resembles most versions today – but also Taylor's prior version. Regarding one of the key attributes of the distinction between probable, plausible, possible, and preferable futures, Voros refers to the taxonomy of Henchey (1978, in Voros, 2003) and the first integration in the futures cone by Hancock and Bezold (1994). Other references to the cone's origin are made to Hawkins' future and past light cone in *A Brief History of Time* (Hawkins, 1988). This emphasises the cones' utility of simple representation (Candy, 2010).

Despite its qualities, the cone has been criticised for its rigid categorisation of the 3Ps, its outer boundary excluding the ridiculous or preposterous, its inability to part ways from a probabilistic, deterministic approach, or its linear time representation (see, for example, Miller, 2011, Candy, 2010, Voros, 2017, Selkirk et al., 2018). The strict distinction between probability, within or via the cone boundary, is an intrinsic feature. However, it has been partially addressed by different or no sub-divisions within and a porous border.

The linear direction, implying both a linear temporal development and a continuous and connected pathway towards the future (instead of, e.g., replacements or ruptures), is the foundation of the cone. There might be ways to integrate it into variations of the cone. However, we did not come across versions of the cone that achieved this or other visualisations that would allow a more precise visual representation of non-linearity. For these reasons, we acknowledge the criticism but regard it for now as an inherent limitation.

Independent of its critiques, the representation has survived, evolved, and still appears in various slide decks, reports, and articles (e.g., Timpe and Scheepers, 2003; Gustafson, 2010; Draeger, 2017; Goodspeed, 2020). Further, its value in representing key conceptual components has been highlighted in studies on the application of futures studies in higher education (Branchetti et al., 2018, Levrini et al., 2021). We have repeatedly tested various versions of the cone outside the futures field throughout the doctoral project with great success. The next section presents the

findings from analysing variants of the futures cone. Afterwards, we compare them to identify how the various cones incorporate different futures characteristics.

Futures cones in literature

We compiled 14 cones through a purposive sampling of either representative or original versions of the most commonly appearing cones to better understand existing cones and their variations. They appeared both in scientific and grey literature. We collected them in parallel to ongoing related work between late 2019 and early 2022. We supplemented the organically growing database through a systematic search for the terms ‘futures cone’, ‘futures funnel’, ‘plausibility/ies cone’, and ‘cone of possibility/ies’ on Google Scholar (103) results and Web of Science (2), as well as via the Google search engine. The author compiled and analysed the cones in regular exchange with the other research team members. All cones in the scientific literature were included if they did not simply show the cone of another author that has been already included. The majority of cones in reports and presentations did not differ from existing cones in literature, even if oftentimes not referenced. In those cases, they were not included either.

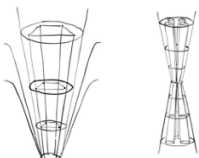
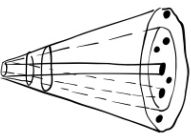

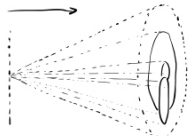
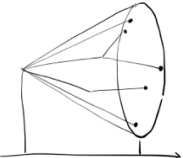
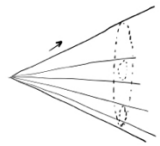
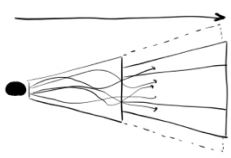
This resulted in 13 different cones, supplemented by two that were further referenced in the other articles. The recent cone of Christophilopoulos (2021) was not included as it does not propose a different cone but instead takes the existing cone and extends it towards another field of application, namely, to contrast futures studies with special relativity theory.

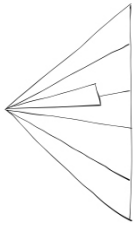
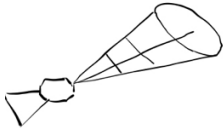
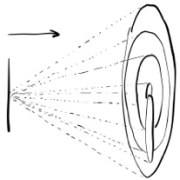
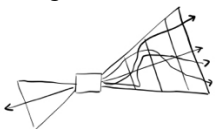
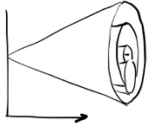
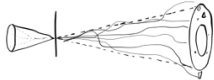
Afterwards, 14 cones are left for analysis (Table 3), from which six are from scientific literature (five articles, one dissertation), six from grey literature (reports and books), and two from online sources. Through their compilation, we intend to ensure that characteristics and components of existing representations are considered. All underlying cones are sketched in Table 3. Despite the attempt to include all relevant cones, the sample does neither claim to be comprehensive nor representative regarding the distribution or occurrence of the cones. As such cones have been used throughout various types of presentations, reports, books, and papers, often with varying or no names, there are inherent limitations. Further, the visual comparison might be affected by the subjective choices of the research team and might lead to different categorisations in a different context.

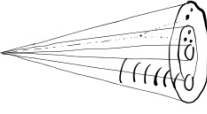
The application context of the cones (Table 3) varies from scientific discussions (e.g., Hancock and Bezold, 1994; Voros, 2003; Candy, 2010; Hines and Bishop, 2013), thematic scenario exercises (e.g., Taylor, 1993; Garret, 1999; Timpe and Scheepers, 2003; Gustafson, 2010; Draeger, 2017; van Dorsser et al., 2018), as well as basic communication of futures studies (Dunne and Raby, 2013; Voros, 2017; Sumaiya, 2018; Levrini et al., 2021). Aside from the compiled sample of cones, we came across most nearly identical simplified cones in presentations and reports to briefly explain how the possible space of the future expands and how scenarios, events, or pathways are situated. Most of them build on Hancock and Bezold’s cone from 1994 or one of the versions of Voros (2003; 2017).

Table 3: Overview and description of set of futures cones (Gall et al., 2022)

Sources & Sketch	Context	Description
Taylor, 1993	The earliest trace of the then ‘cone of plausibility’ acted as a visual reference to explain the process of developing different	The cone, the only one oriented vertically, opens from the today to a larger range of plausible futures, containing the linear pathways of four scenarios, associated to four dimensions (sociological, economic, political, and technological). Outside the cone, four wild

Sources & Sketch	Context	Description
	scenarios for a 'new world order of nations' to decision-makers.	card scenarios (aberrant, disruptive, catastrophic, anomalous) are shown. The temporal scale is ranging from 'today' (1990) to 35 years (2025). A second, simplified version shows the past via a second cone, including the equivalent number of plausible pasts.
<p>Hancock and Bezold, 1994</p> 	Hancock and Bezold, following a consultation for the WHO, published a scientific article on possible and preferable health futures, explaining simultaneously concepts of futures to an external audience and discussing health-related elements, naming it the 'futures cone'.	The cone is oriented horizontally with the time axis from left to right. The cone opens, showing various scenarios at the final plane, including wildcards and alternative futures (possible futures, plausible, and probable futures, as well as one preferable future). The time axis shows a short-term interval at 1-3 years, and a medium-term interval without timeframe.
<p>Garret, 1999</p> 	A few years after the article from Hancock and Bezold, Garret produced a similar cone, titled the 'cone of possibilities', also for the context of health futures in a guidebook, yet with significant differences.	The cone shares the same overall characteristics. However, it defines the inside of the cone as 'all believable futures', has an 'extrapolated future' at the centre, as well as a randomly distributed combination of several wild-card and other probably futures, as well as one 'most likely future' (not the extrapolated future) and one desired future. There is neither the graphical distinction of probability as in the previous version, nor anything between the present and the futures plane, except a straight line connecting the present to the extrapolated future.
<p>Voros, 2003</p> 	Referencing Hancock and Bezold, Voros brought the revised futures cone to the scientific literature of futures studies as part of 'a generic foresight process framework'.	The cone goes from the 'now' to the future and distinguishes between possible, plausible, and probable futures. At the centre is the business-as-usual (BAU) future. Spanning the BAU to possible area, an area of preferable futures is shown. Outside of the possible futures appear to be the 'potential' futures, thus forming five instead of three Ps as well the BAU.
<p>Timpe and Scheepers, 2003</p> 	Without any reference, Timpe and Scheepers present the 'scenario funnel' for a research deliverable on distributed energy generation scenarios for the European Commission.	The cone, despite the lack of a reference, resembles previous version insofar as it has the 'today' at one side, and a futures plane at a later point. Within that plane, several plausible future states are visualised. An interesting addition is the portrayal of non-linear pathways between the 'today' and each future state, with path deviations due to 'disruptive events' and bifurcations at 'decision points'.
<p>Candy, 2010</p> 	Candy used a simplified version of the futures cone in his dissertation to discuss the permeable limits of the possible, named the Clarke-Dator boundary.	The cone starts from the 'now' and distinguished between probable, possible, and preferable futures. The outer boundary is portrayed as permeable, and the preferable futures are spanning the possible and 'non-possible' futures.
<p>Gustafson, 2010</p> 	Gustafson shows a more elaborated cone, referring to the work on global strategic trends by the Development, Concepts and Doctrine Centre (DCDC) of the UK Government. He does so as part of a review of horizon scanning and forecasting in the British intelligence community.	The cone shows a time-axis of 30 years. The first 15 years are shown in one colour, while the next 15 years are divided into plausible, alternative, and probable futures, resulting in 'divergent outcomes'. The focus lies on various non-linear trends within the cone, as well as shocks/events shown as lightnings in the cone. The trends are divided into dimensions, namely 'resource', 'social', 'political', 'technological', and 'military'. In contrast to, for example, Timpe and Scheepers' (2003) cone, the focus is thus on trend trajectories instead of scenario pathways.

Sources & Sketch	Context	Description
Dunne and Raby, 2013 	Dunne and Raby published a book on speculative design in which they present various tools and ideas around design fiction. They showcase a cone in reference to a presentation of Stuart Candy in 2009.	The cone resembles the standards cones by opening from the 'present' to possible, plausible, and probable futures, in this case with preferable futures at the interface of probable and plausible futures. A major difference is the 2-dimensional representation. The cone became a triangle.
Hines and Bishop, 2013 	Hines and Bishop present the futures work the 'Houston way', and refer among others to their futures cone which thus might be from an earlier age. The main goal appears to be the showcasing of various levels of plausibility, as well as the contrast to 'baseline futures'	The cone starts from the 'present' and goes towards 'alternative futures', with a 'preferred future' and 'baseline future' very close to each other (not evident if meant as the same). The cone is bordered by the 'limit of plausibility'. The first time since Taylor's cone in 1993, the cone extended to a 2-dimensional past cone, yet without explanation.
Voros, 2017 	In an extended version from his first (2003), Voros developed a more elaborated cone which today appears in various publications and presentations. It serves primarily to communicate overall concepts, as well as better distinguishing between different levels of plausibility of futures.	The futures cone again has the key characteristics, with 'everything beyond the present moment' being a 'potential future'. Voros distinguished from outer to inner cones between 'preposterous', 'possible', 'plausible', 'probable' and within the probable 'the "projected" future'. The 'preferable' future spans all areas. The porous boundary refers also to the Clarke-Dator boundary introduced by Candy in 2010 and adds the term for it: the preposterous future.
Draeger, 2017 	In an online article, Draeger describes scenarios for disaster preparedness and introduces different concepts, including a cone, referencing Voros and Taylor.	The cone (or rather two 2-dimensional triangles), show 'the present' and the future with different temporal sub-steps, the bordering 'limits of what's plausible' and four scenario pathways (alternate future 1, expected future, preferred future, alternate future 2), each with a non-linear trajectory. The past cone is contained by 'limits of evidence' and 'limits of interpretation' and points towards 'historical facts.'
van Dorsser et al., 2018 	In an article that aims to improve the link of the futures field to policymaking, van Dorsser et al. present a cone that refers to Voros (2003, 2017) and Hancock and Bezold. The cone acts again as a tool to distinguish between different levels of plausibility of futures.	The cone starts at the 'now' and divides between the 'possible', 'plausible', 'probable', and 'projected' futures, the latter being at the centre and within the 'probable'. The 'preferable' future spans 'probable' to 'possible' futures.
Sumaiya, 2018 	This cone appears in an online, explanatory video, that cannot be clearly attributed. Its variations justify nevertheless the inclusion.	The cone opens with a porous cone towards the future, with the 'limit of possibility' at the outside and 'driving forces' in the inside. An intermediary 'planning horizon' is portrayed at three years. At the futures plane, different scenarios are shown with varying but not clearly defined levels of plausibility. A variety of non-linear trajectories are shown within, even crossing the cone limits. The past is portrayed as a cone with several trajectories.

Sources & Sketch	Context	Description
Levrini et al., 2021 	The last cone is used in the context of climate change and futures teaching.	The cone resembles the other insofar that it shows the 'today' and 'possible', 'plausible', and 'probable' futures. It shows 'desirable' futures between the 'plausible' and 'possible' futures. Scenarios are shown in each area. One bifurcation point is portrayed on the otherwise linear pathways. The highlight of the cone is the signal that is sent back from the desirable future towards today, referring to backcasting and the role of defining desirable future.

After compiling and analysing the characteristics of each cone, we developed a comparative matrix that contains all characteristics found in at least one of the cones (Figure 21). All cones are based on (1) linear temporality and (2) a widening range of possibilities, and most make (3) a distinction between various levels of probability. However, the characteristics 4-11 are only made explicit by some, implicit by others, and are absent in the remaining ones (Figure 21). The comparison highlights that most identified characteristics can be represented in the cone. However, simultaneously all representations vary in 9 out of 11 criteria and thus demonstrate little consistency.

CHARACTERISTICS	REFERENCE	Taylor, 1993	Hancock and Bezold, 1994	Garret, 1999	Voros, 2001 in Barber, 2006	Voros, 2003	Timpe and Scheepers, 2003	Candy, 2010	Gustafson, 2010	Dunne and Raby, 2013	Hines and Bishop, 2013	Voros, 2017	Draeger, 2017	van Dorsser et al., 2018	Sumaiya, 2018	Levrini et al., 2021
1. Linear temporality	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
2. Widening range of possibilities	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●	●
3. Distinction between probability	●	●	●	●	●	○	●	●	●	○	●	○	●	●	●	●
4. Exclusion of "likely" future	●	○	○	○	●	●	●	●	●	○	●	●	●	●	●	●
5. Porous boundary of the possible	●	○	○	○	○	○	●	●	○	○	●	○	○	○	○	●
6. Multiple, non-linear trajectories	○	○	○	○	○	●	○	○	○	○	○	●	○	○	○	○
7. >1 trajectories for 1 outcome	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
8. Multi-dimensional scenario sphere	●	●	●	●	●	●	●	○	○	●	●	○	●	●	●	●
9. Wild Cards	●	●	●	●	○	○	○	○	○	○	○	○	○	○	○	○
10. Backwards temporal influence	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○	●
11. Past influence	●	○	○	○	○	○	○	○	○	○	○	●	○	○	●	○

Characteristics are ● explicit ● implicit ○ absent

Figure 21: Comparative matrix of inclusion of scenario characteristics in various futures cones (Gall et al., 2022)

Discussion

This work aims to analyse the existing versions and make recommendations for possible improvements – primarily to enable its more widespread and standardised use. We combine the earlier introduced set with proposed characteristics (Figure 22) to support this process. They include the three (mostly) common characteristics (1-3), the eight characteristics from the sample set of cones (4-11), and three newly proposed ones (12-14). None of the existing characteristics was left out as the goal was to produce a comprehensive representation of concepts. Even if this might lead to a rather complex visualisation, the proposed cone acts as a version that can be simplified according to the case of application.

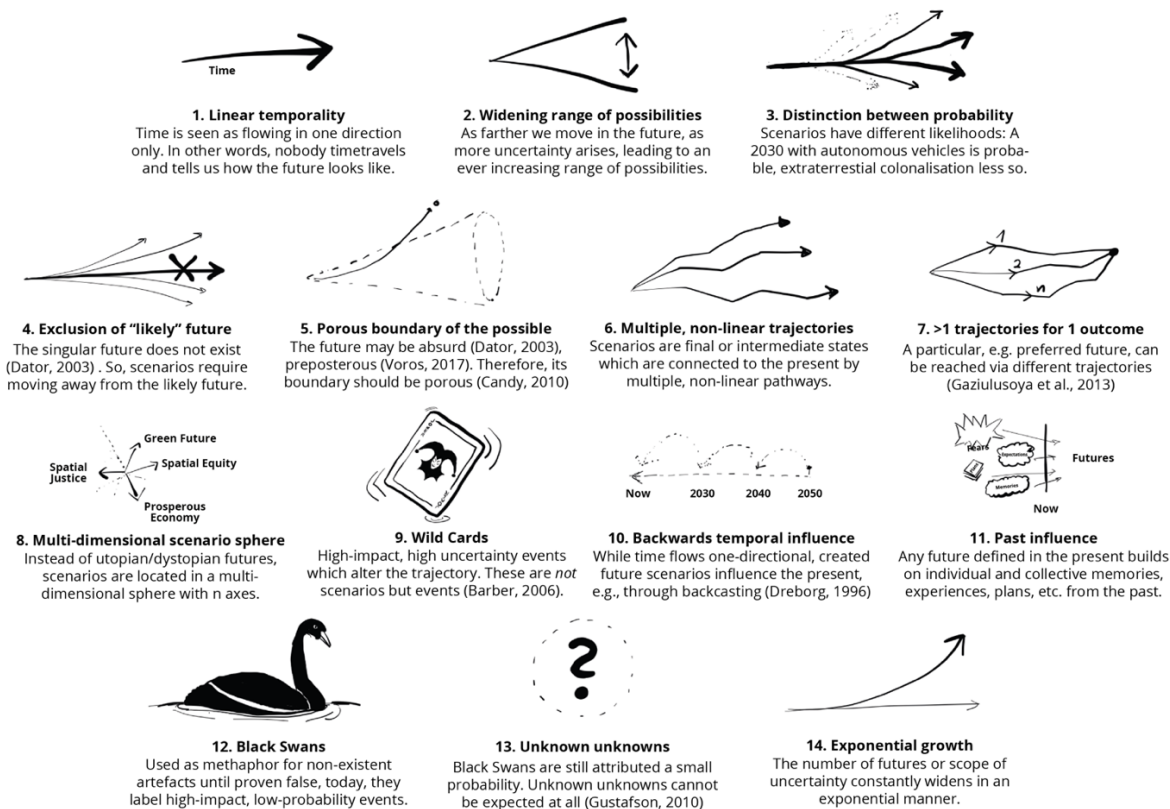


Figure 22: Identified key characteristics of futures cones (1-3 shared, 4-11 existing, 12-14 proposed; Gall et al., 2022)

The newly proposed ones are (12) *Black Swans* and (13) *Unknown unknowns*, as well as an (14) *Exponential growth* of possible futures. Black swans are included as the concept has been used extensively in the futures field (Taleb, 2007; Voros, 2017; Tiberius, 2019; Inayatullah, 2013; Sanhueza-Aros et al., 2022; Gustafson, 2010; Candy, 2010), often in combination with wild cards.

The introduction of unknown unknowns follows the same logic as black swans: An existing concept in futures studies that so far was not visualised. Further, it corresponds with preposterous futures, outside the Clarke-Dator boundary and thus complements another existing component of the cone.

The last characteristic, exponential growth, is introduced primarily as a geometrical correction aligning the concepts with the graphical visualisation. It is translated into a shape that changes from a traditional cone (exponential growth of cone opening surface area) to an exponentially expanding cone if seen in a section view. This allows for a higher representative accuracy as the trajectory within the space of possibility can change its direction continuously and always 'carries' a traditional cone along (see Figure 23). Thus, the exponentially expanding cone appears as a possible adaptation that considers several trajectory reconfigurations within the overall cone. It provides continuously more possibility space across multiple axes.

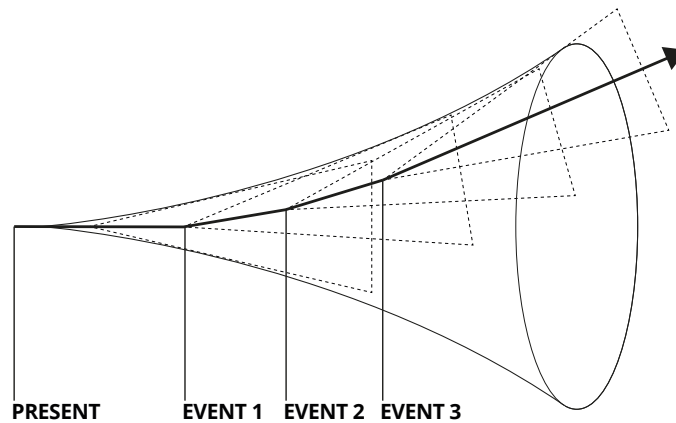


Figure 23: Simplified geometrical representation behind idea of the exponentially expanding cone (Gall et al., 2022)

For a more detailed description, each characteristic is explained in detail in Table 4.

Table 4: Description of characteristics of futures cone (Gall et al., 2022)

	Characteristics	Descriptions
Core characteristics	1. Linear temporality	The first of the three common characteristics is that time is seen as flowing in one direction only, namely forward. While various discussions around this exist as well, futures studies, planning, design, and most other disciplines are building on this. Thus, it is seen as key element and – aligned with traditional representation of time series – visualised as a linear flow from left to right.
	2. Widening range of possibilities	The starting point for the ‘cone’ was the representation of an ever-increasing range of possibilities. In five years, various futures are possible. However, in 50 years, the possible range is a multiple thereof. Thus, the cone opening towards the future allows to represent one of the key ideas of futures thinking.
	3. Distinction between probability	The last core characteristics is the differentiation between probabilities or plausibility. Regardless of the field, different likelihoods are oftentimes assigned. In the case of the futures studies, it appeared in Henchey (1978) and was integrated in the second cone in 1994 by Hancock and Bezold, intensively discussed by Voros (2003; 2017) and appears today in nearly all visualisations.
Compiled characteristics	4. Exclusion of ‘likely’ future	One key concept of futures studies is the non-existence of the singular most-likely or expected future, expressed famously by Herman Kahn as ‘the most likely future isn’t’ (Kahn, 1982; cf. Dator, 2019). Thus, scenarios require moving away from the likely future. However, the forecasting and foresight often overlap in practice. Therefore, many most-likely futures or Business-as-Usual scenarios continue to exist, even in distant future contexts. This is a fact that we consider one of the most challenging inconsistencies in existing visualisations.
	5. Porous boundary of the possible	While the idea of the cone is to provide ample space for future possibilities, from its first version (Taylor, 1993) the cone was not seen as a strictly limiting boundary. As Dator (2003) argues, the future may be absurd, or to follow the P-vocabulary logic, preposterous (Voros, 2017). Therefore, its boundary should remain porous (Candy, 2010) to not limit possible thinking within a restricted geometrical shape.
	6. Multiple, non-linear trajectories	Some cones do not show scenarios at all, some visualise them in various places at the finale futures plane or as linear or non-linear pathways. We understand scenarios as alternative and intermediate states which are connected to the present by multiple linear pathways representing the trajectory that would need to be followed to reach a particular future state. As the ‘present’ is not seen as an object that once in motion does not change anymore but one that is constantly realigned, the trajectory can be considered non-linear (cf. Timpe and Scheepers, 2003; Draeger, 2017; Levrini et al., 2021).
	7. More than one trajectory for one outcome	The previous point discussed the purpose between portraying trajectories between the ‘today’ and a possible future state. Gaziulusoy et al. (2013) among others argues, that different trajectories can potentially lead to the same outcome. Thus, we are looking at and integrating cones that consider more than one trajectory for any particular scenario.

	Characteristics	Descriptions
	8. Multi-dimensional scenario-sphere	While some scenario sets are made of one BAU, and two extremes on a singular scale, most scenarios – primarily in the futures field – do not discuss dichotomous futures such as utopias and dystopias. Instead, they look at scenarios that have different characteristics across dimensions (e.g., social, environmental, economic). We summarise this element as a visual representation of scenarios on a multi-dimensional sphere/plane.
	9. Wild Cards	Wild card scenarios appeared already in the first cone by Taylor (1993). In other contexts, wild cards refer to high-impact, high uncertainty events which alter the trajectory (e.g., Barber, 2006). They can theoretically be co-located with the scenario at a specific time in the future. However, more likely is the wild card occurrence at any point along the trajectory, Thus, wild cards are primarily not understood as scenarios but events.
	10. Backwards temporal influence	As visualised by Levrini et al. (2021) and connected strongly to backcasting (Dreborg, 1996), time flows one-directional but possible futures can influence the present. A fear of a future may lead to certain actions, or a preferred one can cause directed action. Thus, the backwards temporal influence is included.
	11. Past influence	Even though most futures start at the ‘now’ without consideration of the past, the development of scenarios, underlying knowledge, experience, paradigms, and trends, among many others, all stem from the past. Thus, the visualisation of the influence of the past can contribute to a more accurate temporal contextualisation of the trajectories of futures.
Proposed characteristics	12. Black swans	Black swans are used as metaphor for artefacts that are assumed to be non-existent until proven real. In the futures context, they are used to label high-impact, low-probability scenarios. A black swan scenario is thus one that is not very likely but if it would become reality, it would have a high impact.
	13. Unknown unknowns	We can still attribute black swan scenarios a small probability and thus considered them a possibility in the scenario making process. On the other hand, ‘unknown unknowns’ cannot be expected at all (Gustafson, 2010). Their visual inclusion can nevertheless make sense as – without being able to predict them – the awareness of their potential manifestation can inform the process through acknowledged uncertainty.
	14. Exponential growth	The last characteristic is proposed in conceptual continuation of multiple, non-linear pathways. If we assume this as a likely concept, at each future time along one possible scenario trajectory, various ‘sub-cones’ become possible, oriented within the cone as new cone that is oriented in parallel to the initial, non-horizonal trajectory. Thus, the scope of uncertainty could be conceptualised as constantly widening in a rather exponential manner than a traditional cone.

Combining characteristics into a revised visualisation

We developed a combined visualisation (Figure 24) building on the key concepts, characteristics, and existing cones. In agreement with the earlier shown cone (Figure 7), it keeps the temporal x-axis, the widening scope, and the distinction of the possible, plausible, probable, and preferred as a category spanning each of the previous. It further incorporates a range of the described characteristics.

We integrated the additional category of preposterous as well as the porous Clarke-Dator Boundary from Voros (2017) and Candy (2010). We extended the preferable/preferred with ‘by Group X due to Reasons Y+Z’ to emphasise the significance of who makes the choice of the preferred future based on what assessment method. We added multiple non-linear trajectories to represent the path from the now to each defined future scenario. More than one trajectory can end in the same scenario (cf. Gaziulusoy et al., 2013). The outer boundary can be crossed by a pathway, ending in a Black Swan scenario. We included an Unknown unknown without a trajectory due to the impossibility of the anticipation of the pathway or outcome. Finally, we added Wild Cards along the pathways at particularly stark bifurcation points (Barber, 2006).

Further, we propose a few variations. First, we extend the time axis into the past. This has been done before (e.g., Taylor, 1993, Hines and Bishop, 2007, Sumaiya, 2008,

Draeger, 2017) but by adding a cone widening towards the past. The cone is used for different purposes in the past (e.g., limits of evidence/interpretation by Draeger, 2017) and future (limits of possibility), which we consider confusing. In that case, the spatial dimension of the cone represents various concepts in the same graphical visualisation. Hence, we represent the past as an impacting element but not a cone. Further, we show an individual past trajectory, which is at its bifurcation point at the 'present'. Another addition is the temporally backwards-directed influence towards intermediate time frames (e.g., every five years) and the present. This builds on the transformative concept of backcasting (Dreborg, 1996) and the cone of Levrini et al. (2021).

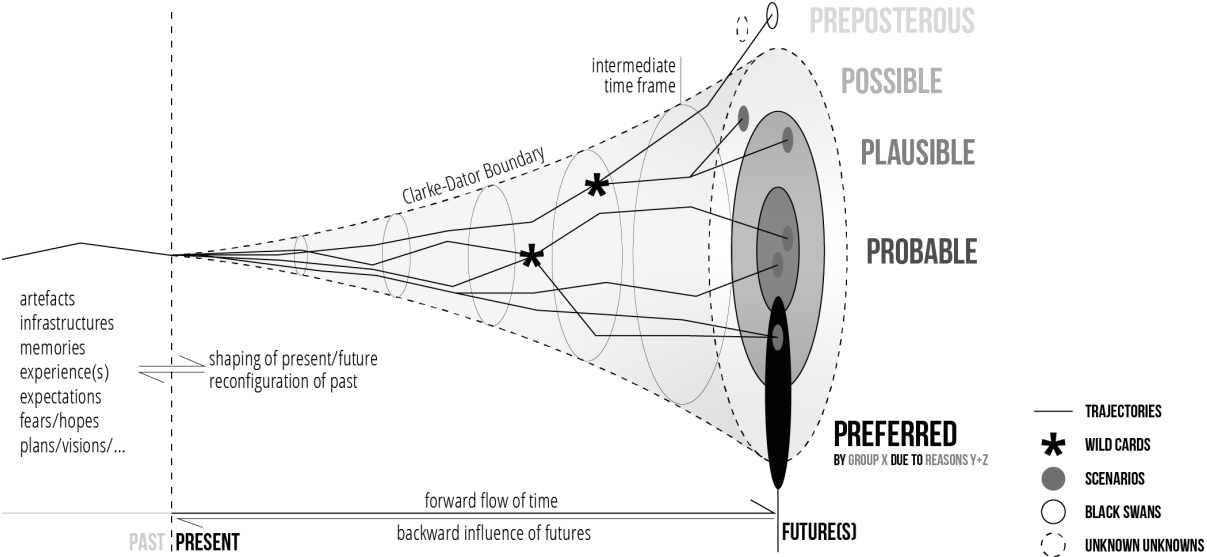


Figure 24: Revised Futures Cone (Gall et al., 2022)

The resulting cone is not meant to be absolute but instead attempts to combine the conceptually consistent characteristics of the 14 analysed cones. This shall provide a foundation for further extensions and adaptations. Further, it shall do justice to the history and contributors to the futures cone. It continues the motivation of many earlier versions of emphasising the non-linearity and uncertainty of futures, for example, via Black Swans and Unknown unknowns, contextually framing scenarios, and making multiple futures visually more tangible. We consider the review of existing cones and their characteristics as our primary contribution. However, we believe the proposed futures cone acts as a more detailed, complete, and aligned visualisation of many of the core concepts of futures studies compared to previous versions. We argue further that it can support the more accurate explanation and teaching of futures concepts. For example, *the cone can help explain the increasing possibilities over time, various scenarios as pathways across time, and the role of specific elements such as black swans, unknown unknowns, or wild cards.* Lastly, the futures cone combines most qualities of previous versions while introducing previously ignored ones. It can thus act as a more complete intermediary object as the foundation for conceptual discussions in the futures field.

Direction of future works

While we incorporated the key concepts, further developments remain inevitable. First, the futures cone is seen as a high-level conceptual representation. A subsequent step could be the zoom-in on individual elements such as the scenario pathways or

trajectories. The Multi-Level Perspective (Geels, 2011) and concepts from transition management theory bear the potential for valuable extensions to detail these further. This could allow considering, for example, scenarios as socio-technical regimes situated within a socio-technical landscape and fed by niche developments. In this context, the futures cone could nourish related fields while being strengthened by elements from their respective concepts.

Additionally, the multi-dimensionality of the sphere of final scenarios is impossible to represent accurately. Nevertheless, it is seen as crucial to attempt. Practical comparisons may be drawn to the Principal Component Analysis and related conceptual approaches to work with more than three dimensions. Explorations of digital three-dimensional visualisations or interactively dismantled versions could provide further prospects.

Lastly, the futures studies field operates between very abstract and challenging theoretical perspectives on the one hand and very tangible strategic foresight methodologies on the other. While the goal cannot be to involve everyone in the depths of the field, increased utilisation of key ideas and approaches across disciplines can contribute to overall futures literacy. To exemplify the use of the revised futures cone, we could envisage working in a team with existing scenarios archetypes (Fergnani and Jackson, 2019). In the first step, we could situate the scenario archetypes within the futures cone. Next, wild cards and black swans could be generated through a creative exercise. Finally, the participants could collectively imagine possible trajectories which are combining wilds cards and black swans to scenarios pathways. This can support the immersion in scenarios as trajectories between today and a set future timeframe. On the other hand, using the cone could allow for continuous validation and expansion of the existing model, as well as widening the input for joint conceptual elaboration.

Intermediate conclusion

This work resulted from the intent to map key concepts of futures studies and visualise them to discuss them with peers and communicate them to external audiences. Our research questions were how the futures cone has been used so far to visualise concepts of futures studies, and how existing and potential characteristics can be consolidated into a revised version. To answer these, we identified 14 futures cones with a wide variety and inconsistency. Further, we provided a contextualised analysis of representations of core characteristics of futures studies.

As a result, we proposed a set of characteristics and a revised futures cone to showcase core components of multiple futures and provide an updated visual reference emphasising nonlinearity and uncertainty. The resulting cone can contribute in three ways:

- 1. It provides a more detailed graphical review of the futures cones of the past, thus providing an easy starting point for new cones.*
- 2. The revised cone is the most complete visualisation to date, thus allowing the easy communication and teaching of numerous concepts of futures studies.*
- 3. The underlying data and cones are made accessible to nourish conceptual and theoretical discussions as a canvas and visual platform.*

We have used the cone throughout the past years effectively for teaching, explaining, and elaborating futures context, and we hope it will allow doing the same for others. At the time of writing this dissertation, the cone has already been taken up by others

and used in presentations, papers, and reports. Nevertheless, various limitations and further work directions are evident and require additional attention. The primary limitation is that every model or visual artefact is inherently restricted by its level of abstraction. A representation of endless possible futures across theoretically all scales and domains is most likely more subject to this than many other models. Nevertheless, while futures studies have no homogenous body of knowledge, different principles, concepts, and perspectives are primarily consistent across literature and time. We attempted to focus on these and showcase them in the revised futures cone. Its simplified visualisation – even if disputable from various lenses – has proved useful in communicating these common ideas to non-experts. For all still contested concepts, the visual artefact of the cone – and future revisions thereof – can act as a canvas to discuss them further.

4.2.2 Futures scenarios and urban mobility systems

The futures cone as model to represent futures scenarios provides a conceptual representation. However, to work effectively with multiple futures, many fields require locality-specific scenarios, for example, when working with urban mobility. The second section of this sub-chapter thus takes the concepts introduced via the cone, scenarios are core element, and the in Chapter 4.1 detailed UMS to present an integrated framework merging scenarios and the three UMS layers with special attention to the earlier introduced current gaps.

Creating specific scenarios is resource-intensive, leading to either no work with scenarios, infrequent updates of the existing scenario sets, generic global scenarios that are not adapted to local contexts, or sub-quality or otherwise inadequate scenarios. On the other hand, a multitude of various scenario sets already exist: General, normative or speculative, topic-specific, or localised ones. Additionally, archetypical scenario typologies have been deducted from existing sets. Dator was first to name ‘Growth, Collapse, Discipline and Transform’ as archetypical scenarios in 1979 (Dator, 2019). Fergnani and Song (2020), among others, built on this concept and conducted a systematic review, ending up with six archetypical scenarios, namely, ‘Growth and decay, Threats and new hopes, Wasteworlds, The powers that be, Disarray, and Inversion.’ Finally, Miskolczi et al. (2021) conducted a systematic literature review on urban mobility scenarios until 2030, resulting in four representative urban mobility scenarios: ‘Grumpy old transport, At an easy pace, Mine is yours, and Tech eager mobility.’ A detailed look at their sample highlight how similar many existing scenarios are. Despite the duality of lack of access to useful (locally) adapted scenarios and a large set of existing scenarios, there has been little discussion on the utility and feasibility to adapt or localise existing scenario sets, with the exception of Lang and Ramirez (2021) who highlight the challenges and potential of reusing scenarios and what must be considered in the process. The methodological discussion of this localisation process will take place in Chapter 5. However, to permit the adaptation of UMS to different scenarios, an integrated methodological framework is necessary.

As a response, we propose the integrated model shown in Figure 25 that overlays a number of scenarios, here the four archetypical scenarios of Miskolczi et al. (2021), with the three layers of UMS, namely People, Infrastructures, and Mobility Services. Additionally, the parallel process of quality assurance, the concurrent or subsequent steps of impact assessment and scenario visualisations, as well as the possible

following impact evaluation are shown. These will also be discussed further in Chapter 5.

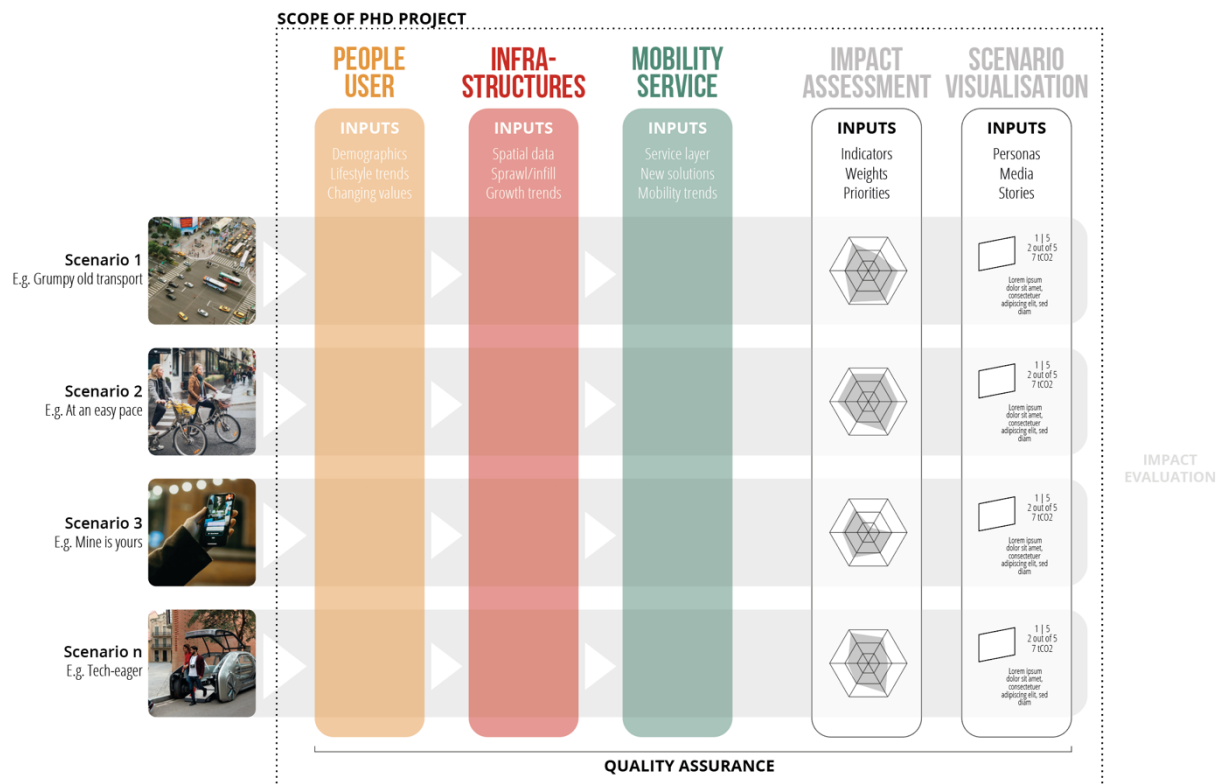


Figure 25: Methodological framework to adapt Urban Mobility Systems (UMS) to future scenarios (CC BY 4.0)

The principal concept behind the model is the iterative adaptation of future UMSs by following a logic of starting with possible future changes of people (e.g., population growth), the impact thereof on infrastructures (e.g., infrastructure extensions), and finally the response of mobility services (e.g., increasing public transport frequency or new bus lines). The order originates from the pace of change of each layer. With exceptions of wars or disasters, demographics as well as people’s social practices and behaviours change slowly. Urban systems as physical manifestations of society – people – react to their population by growing, sprawling, shrinking, or otherwise adapting. Mobility services are the fastest to adapt and are a function of people and infrastructures. For example, a bus line is routed depending on where how many people live and work, and what road infrastructure and competing or complementary rail infrastructure is available. While one should remember that this is a simplified model, potentially restricted by dominant plans or policies or nested interests, we postulate that the model permits within these limitations to adapt UMS for a set of scenarios. After zooming in the next section into the modelling and adaptation of the people layer, we apply and test the hypothesis of this model’s utility in the context of the two case studies in Chapter 5.

4.3 Modelling future urbanites

Research question	How to model future urbanites?
Methodology	Mixed-methods, qualitative research incl. literature review, interviews, and workshops.
Results	This section results in a range of approaches to model users and people is introduced and results in a joint representation.

Contributions

Implications

Reference articles

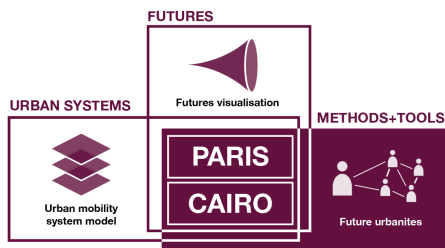
c) Integrated urbanite model for people-centred design.

The theoretical side, the definition and conceptual modelling of people-centred design and its consideration across time and space permits a clearer distinction between existing design frameworks and a structured comparison between design methods and their objectives.

Gall, T., Vallet, F., and Yannou, B. (2023) Comment concevoir des systèmes de mobilité urbaine pour les citoyens du futur ? Époque 07/2023.

Gall, T., Chouaki, T., Vallet, F. and Yannou, B. (2023) Considération des incertitudes et tendances dans la simulation multi-agents de la mobilité : Apport des scénarios futurs. s.mart colloque.

There is a lack of systematic integration of future users in current design processes of urban mobility solutions, as well as the people who are or will be affected indirectly. As we are talking about mobility in a predominantly urban context, we refer to these people as urbanites. The most common models are synthetic populations (SP) for quantitative design methods such as multi-agent simulation (Hörl and Balac, 2021)



and personas for qualitative methods (Vallet et al., 2020). These approaches have, until now, been used separately and have little integrated uncertainties about the future such as the evolution of preferences, mobility needs or technologies.

The question how to design urban mobility systems for the urbanites of the future arises. To answer this, we use the existing personas and approaches for their adaptation to future contexts to create SPs of the future, and thus have a set of qualitative and quantitative representations of the city dwellers of the future, to reflect the design and simulation of solutions today. In this sub-chapter, we describe the background, the archetypal scenario-based approach (Miskolczi et al. 2021) for designing with uncertainties about the future, followed by a description of the method and the main characteristics of future urbanites.

The application context is that of urban mobility, which we model as a complex adaptive socio-technical system (cf. Chapter 4.1). The key components that structure it fall into three categories: people, infrastructure and services, which relate to each other and can be used to model future UMS.

To integrate the vision of the future into a structured approach, we use scenarios that allow us to work with multiple possible futures (cf. Chapter 4.2). These future scenarios are based on trends and uncertainties. Trends are assumed to materialise while the realisation of uncertainties is unknown. In combination with the modelling of the urban mobility system, we arrive at the approach presented in Figure 25 (Chapter 4.2). Through a set of predefined scenarios, we adapt future UMS, starting with the projection of people, followed by the adaptation of infrastructures, and finally the mobility services.

We start by adapting the first layer of the urban mobility system, people or more precisely *future urbanites*. Various design approaches exist to design with, for, or by people. Yet many common participatory approaches are not appropriate when working with future urbanites. So, we can mainly try to design for people. Instead, we

rely on people-centred design as we aim to integrate all urbanites, users and non-users, and prioritise systemic impacts (Gall et al., 2021b). Building on a joint theoretical framework (Vallet et al., 2022), they are combined into an integrated approach to support the process of integrating future uncertainties via scenarios in people-centred design approaches (Gall et al., 2023a,c).

Designing for future urbanites

We propose a method to integrate a representation of future urbanites into the design process, using both qualitative and quantitative design models. Table 5 lists some of the key characteristics relevant for the design of urban mobility systems that are common to personas and SP approaches and allow the link between the two (Gall et al., 2023b).

Table 5: Characteristics of urbanites relevant to the design of urban mobility systems

Category	Characteristics	Description / Relevance
Descriptive	Age/Gender	With each age/sex group, the possible options change.
	Socio-economic category	Socio-economic characteristics define choices/resources.
	Activity chain	Activities are work/school, shopping, leisure and appointments and are the basis of mobility as a derived need.
	Activity locations	The places of the activities define the duration and the possible modes.
	Times of activities	Times vary over a 24-hour day and may impact which modes are available or preferred.
Resources	Household characteristics	Individuals in households can share vehicles, travel, or lead to increased demand.
	Available vehicles	The type/number of vehicles defines the possible modes.
	Driving license	Permits/abilities define possible modes.
Preferences	Transport pass/ticket	Having unlimited access can define the prioritization of modes.
	Value of time/money	Different people value time and money differently.
	Mode preferences	Different people prefer one mode over another, for example due to ecological values.
	Availability of information	People have access to different levels of information, so differ in their knowledge of ‘optimal’ routes.
Constraints	Willingness to change mode	The change of mode (intermodality) is perceived differently.
	Willingness to share	Some are more willing than others to share modes.
	Different capacities/security	Some have reduced mobility or safety concerns.

To collect data on how these characteristics might change in the different scenarios, we applied a mixed approach, conducted six expert workshops and 16 interviews (see Annex AN.3), and explored academic and grey literature. The academic literature has shed light on future global trends to consider, such as demographic changes. Grey literature, for example that of local authorities, has informed about the profiles of personas that could develop in certain areas. Expert interviews were conducted to

gather specific information from local and international experts. This mainly includes qualitative information on possible developments in urban development, mobility, technology and social practices that are subject to change. In the workshops, locating trends and uncertainties was facilitated by creating a set of predefined personas (see Annex AN6.3 for examples). The joint use of this information allows us to make a localised adaptation of a set of pre-existing archetypal urban mobility scenarios in a first step.

Then, we use the localised scenarios to adapt the characteristics of future urbanites to each of them. For example, we can increase the population and the average age, vary the ecological values and the number of cars per household. This allows us to build personas and SPs that are consistent with each other and specific to each future scenario. This integration is carried out by scaling and adapting the SP by an updating algorithm to have different occurrences of models and activity profiles at the output of each of the scenarios. The parameters that change are some of the parameters listed in Table 5. In the case of France, these data come from the census, mobility surveys and INSEE forecasts.

We have presented the key elements of an approach to designing urban mobility solutions for future city dwellers in a given geographical area. We apply it to test the usefulness of shared urban mobility services in Paris-Saclay and evaluate potential public transport options in Cairo. Although limitations are present, such as the difficulty of validation due to future scoping, we argue that the approach has advantages to make the design of future solutions more robust. The association between personas and future synthetic populations had not been explored to our knowledge until now. The joint approach allows an individualised projection of useful uses in design, but also aggregated at the scale of a geographical area for the simulation. While focusing on the case of urban mobility, we believe that the approach can find application in the design of other urban systems, such as energy systems or housing.

Urbanites in mobility simulations

Activity-based frameworks permit detailed simulations of mobility behaviour with a specific focus on the moving individuals (cf. Chapter 2.3). In this work, we use the open-source, multi-agent transport simulation framework MATSIM to simulate future UMS (Figure 26). It permits modelling urban mobility based on individual agents, thus people living and moving in a particular area, during a full standard weekday (00:00-23:59), taking into consideration the road and public transport network, its, via the General Transit Feed Specification (GTFS) standardised, schedule, locations of work, education, commerce, etc., as well as an underlying choice model. Calibrated via actual numbers or aggregate values, this makes up a set of input values that are fed into the model. This is run n iterations (e.g., 100) to find an equilibrium for the scoring factors (e.g., reduction of time and expenses). After each iteration, maximum 5% of the simulated population can change their choice to improve their individual utility.

Due to the high computational requirements to simulate many iterations of the daily movements in large metropolitan regions with a population of many millions, the SP are oftentimes proportionally downscaled via random sampling. While this reduces the accuracy of the results, it allows to run more complex and exploratory simulations. Further, it is important to note for which fields of application MATSim bears advantages. The fact that it permits modelling on the individual level invites any kind of applications that tries to understand different profiles and – importantly – their interaction via

congestion or shared use of shared mobility modes. Thus, it fills a gap between higher level models such as the Four-Step Travel Model which models aggregated demand, or higher detail models looking at intersections or any forms of mobility where mobility space is conceptualised more accurately as lines and nodes with defined capacities. The set of future SPs described in this sub-chapter build one of the principal inputs for the agent-based simulations (Figure 26).



Figure 26: Simplified visualisation of inputs and outputs of MATSim (CC BY 4.0)

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**To design is to devise courses of action aimed at changing
existing situations into preferred ones.**

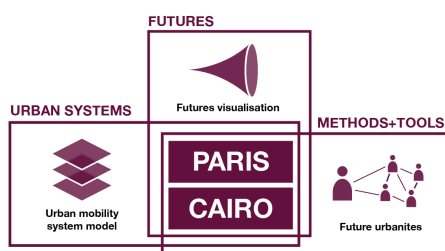
Herbert Simon, Nobel Prize Laureate

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5 DESIGN TOOLBOX: METHODS FOR FUTURE URBANITES

Research question	How can design processes of people-centred mobility solutions for future urban systems be supported?
Methodology	Mixed methods.
Results	Localised urban mobility scenarios, personas, and synthetic populations as intermediary design objects. Two methods to compare and assess potential urban mobility interventions in local context while integrating uncertainties.
Contributions	<ul style="list-style-type: none"> a) Tested and replicable method for localising scenarios. b) Tested and replicable method for integrating scenarios in agent-based simulation. c) Tested and validated support tool for rapid sustainability impact assessment of urban mobility solutions with focus on personas and futures.
Implications	Practical implications of this sub-chapter include the simplified reuse and localisation of scenarios, the use of the created and accessible intermediary design objects, as well as the structured integration of future uncertainties on the people-layer in agent-based simulations.

This chapter describes the development and application of three methods to 1) localise scenarios, 2) integrate scenarios in agent-based simulation, and c) perform a rapid sustainability impact assessment of urban mobility solutions with focus on personas and futures. While each method will be described in the following, a short contextualisation in connection to the chapter title of ‘design toolbox’ is provided. We understand *scenario-based design of solutions for urban systems as an adaptive and integrated set of design processes*. For some steps, e.g., creating scenarios or personas, a solid methodological foundation already exists. In other compartments of the toolbox, e.g., localising existing scenarios, we identified potentials for new methods. Using the two geographical contexts of Paris and Cairo, this chapter details how the methods are developed, tested, validated, replicated, and build on or extend existing methods.



To do so, the two geographical contexts and application case studies are introduced. The first geographical context of Île-de-France with focus on the inter-council partnership Paris-Saclay (CPS¹⁷) constitutes the central focus while the case of the metropolitan area of Greater Cairo acts as a replication and validation context. The terms used

to refer to both areas change but always mean the continuous urban areas regardless of administrative boundaries.

In France, the focus lies on an administrative entity south of Paris which, however, is strongly inter-connected with its surroundings. We conduct the studies at the *regional*

¹⁷ FR: Communauté d’Agglomération Paris-Saclay

level of Île-de-France while focusing on the urbanised central areas where most of the population resides.

In Cairo, different and evolving governates (mostly Giza west and Cairo east of the Nile) and different administrative layers form the metropolitan area whose extent is difficult to define due to continuous settlements in North-South direction along the Nile and over 60 years of new town developments in the desert in the east and west, with complex underlying land administrations.¹⁸ We refer in the following to (Greater) Paris when talking about the continuously urbanised area in the Île-de-France region, CPS for the administrative inter-council partnership and (Greater) Cairo when talking about the equivalent in Egypt. To add a layer of complexity, in Arabic Cairo is commonly referred to as Misr (مصر), the name for Egypt, highlighting both its dominant national position and the challenge of clearly defining its geographical extent. Or in David Sims' words: 'Cairo is Egypt and Egypt is Cairo' (Sims, 2012, p. 24).

As described in the Research Methodology chapter, this project follows a grounded theory approach. In practice, this means that the two presented case studies have not been conducted before or after the method development but have been an integral part of the process.

Especially the Paris case study run in parallel to the overall doctoral project while Cairo mostly acts as replication context. Therefore, this chapter combines the presentation of the design toolbox for future urbanites by introducing the case study work where its components have been created, replicated, and validated. Figure 27 highlights this chapter's position, building like the previous one on the literature review and research methodology chapters. Following this introduction, we outline the Paris case and present the developed and applied methods. This entails the *localisation of future scenarios* and the *scenario-driven creation of sets of personas and synthetic populations*. These methods are thereafter applied to two complementary assessment approaches which aim to compare the impact of potential future interventions in the local context of Paris-Saclay. This is followed by the introduction of the second case study of Cairo and the presentation of the methods' replications. Finally, a summary and discussion of the developed approaches focuses on the methodological contributions across the case studies.

¹⁸ A choice on the geographical extent has been made in collaboration with local experts which is presented in the subsequent sections.

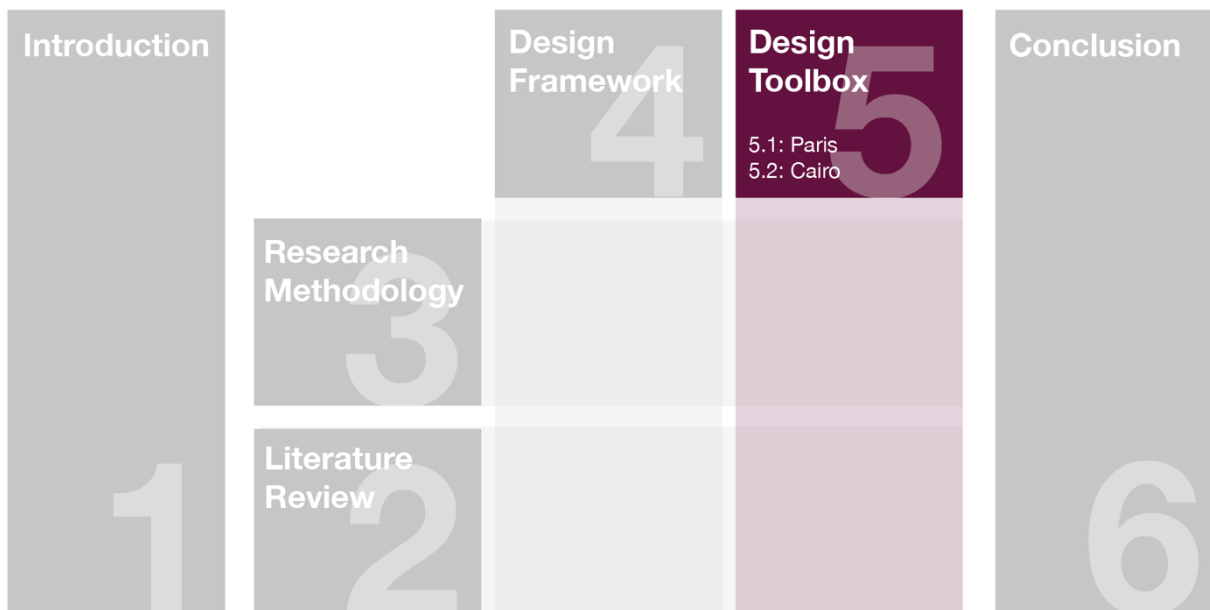


Figure 27: Dissertation structure: Content of chapter 5 (CC BY 4.0)

5.1 Co-creation of design support methods in Paris

Research question	How can design processes of people-centred mobility solutions for the future urban system of Paris be supported?
Methodology	Mixed-method case study, using qualitative (i.e., interviews, workshops) and quantitative methods (i.e., k-proto clustering, iterative proportional fitting, agent-based simulation, interactive decision support tool).
Results	A set of localised urban mobility scenarios, personas, and synthetic populations as intermediary design objects. Two methods to compare and assess potential urban mobility interventions in local context while integrating uncertainties.
Contributions	<ul style="list-style-type: none"> a) Method for localising scenarios. b) Method for integrating scenarios in agent-based simulation. c) Support tool for rapid sustainability impact assessment of urban mobility solutions with focus on personas and futures.
Implications	Practical implications of this sub-chapter include the simplified reuse and localisation of scenarios, the use of the created and accessible intermediary design objects, as well as the structured integration of future uncertainties on the people-layer in agent-based simulations. The latter is already in use or considered for other projects.
Reference articles	<p>Gall, T., Vallet, F., Ben Ammar, M. and Yannou, B. (2023) Designing solutions for uncertain futures: A checklist for choosing suitable scenarios. ICED23.</p> <p>Gall, T., Hörl, S., Vallet, F., and Yannou, B. (2023) Integrating future trends and uncertainties in people-centred urban mobility design via data-driven personas. European Transport Research Review [forthcoming]</p>

This section introduces the region of Paris, its development, growth and changing roles in history. With a history of 2,000 years, its heritage, and a significant existing built and infrastructure stock, any consideration of potential futures builds on the

existing; understood as a continuation and alteration of past trends and patterns without implying path dependency. We describe different administrative and functional entities which culminate in the Paris region, relevant for understanding territorial trends, as well as choosing the adequate geographical scope for different considerations of the future. This section ends with a short outlook into the already planned future of Paris, in particular the existing plans and ongoing projects.

Within the framework of the Anthropolis Chair, the simulation parts of this work were conducted with Dr Sebastian Hörl who generated the SP for each scenario, and Dr Tarek Chouaki who implemented the future public transport (Chouaki, 2023) and conducted the simulation of the scenarios.

Data and source code

All data is open source, and the process is fully replicable.

Simulations:

Synthetic population inputs: <https://github.com/TjarkGall/proto-persona-clustering>

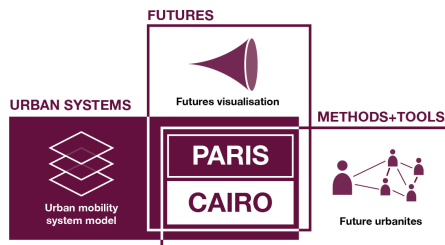
Existing MATSim pipeline: <https://github.com/eqasim-org/ile-de-france> (Hörl and Balac, 2021)

Tool:

Prototype: <https://urban-framework.com/scenario-tool>

Source code: <https://github.com/TjarkGall/decision-tool-interface/tree/main>

5.1.1 Case study description of Paris



A large part of the research is carried out in the region of Paris with special interest in the southern area of Paris-Saclay. In this section we make use of the previously introduced UMS to describe the past and present situation as well as some of the planned developments and trends which will feed into the scenario localisation.

We start with the layer of people, followed by infrastructures, and services. The section on people describes the current demographics and socio-economic situation of people living and working in Paris, as well as future certain and uncertain future developments and social dynamics. In the infrastructures section, the built environment and physical infrastructure relevant to urban mobility is introduced. Finally, the services section focuses on principal current and potential future mobility services to provide a context of how people are moving today.

5.1.1.1 People of Paris

Foremost, an urban area is a habitat for its residents, and urban mobility deals with the movements of them within the urban area. Hence, the number and types of residents in any area has a significant impact on future mobility, as well as various determining factors such as housing markets or unemployment. Currently, the region of Paris has 12,4 million inhabitants, with just over 2 million in the city of Paris (INSEE, 2022).

The global population is assumed to come to a halt and possibly reverse around the next turn of the century. Already today, many countries in the Western hemisphere do

not experience further population growth. Instead, the strongest growth is taking place on the African continent. While the growth in France also slowed down, an overall growth is still anticipated to continue for the next decades, combining factors of natural growth and immigration. In the case of the IDF and other urban areas, population growth further stems from ongoing urbanisation (Figure 28).

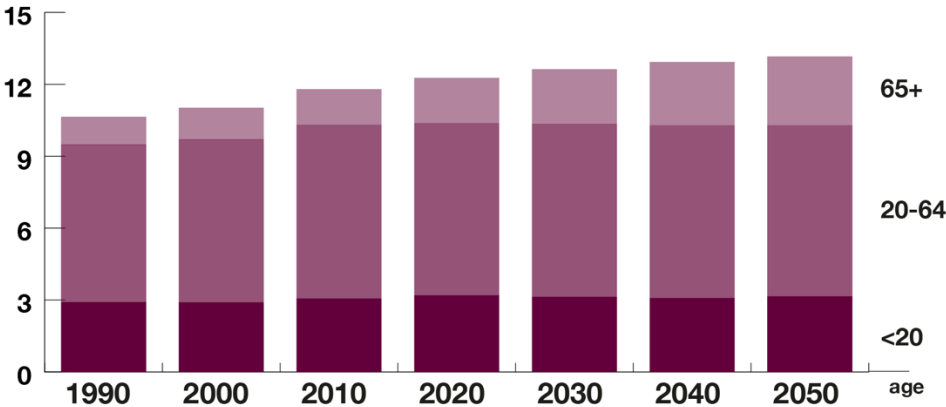


Figure 28: Projected population growth IDF 1990-2050 by age group (INSEE, 2017)

The slowing growth combined with better health care and increasing life expectancies results in an ageing population. Figure 28 above shows the projected population of the IDF from 1990 until 2050, including the age groups. The overall population only grows from a bit over 10 million to about 13 million. However, the group of over 65-year-olds more than doubles in the same period. This change of the demographic pyramids is further portrayed for three periods in time in Figure 29.

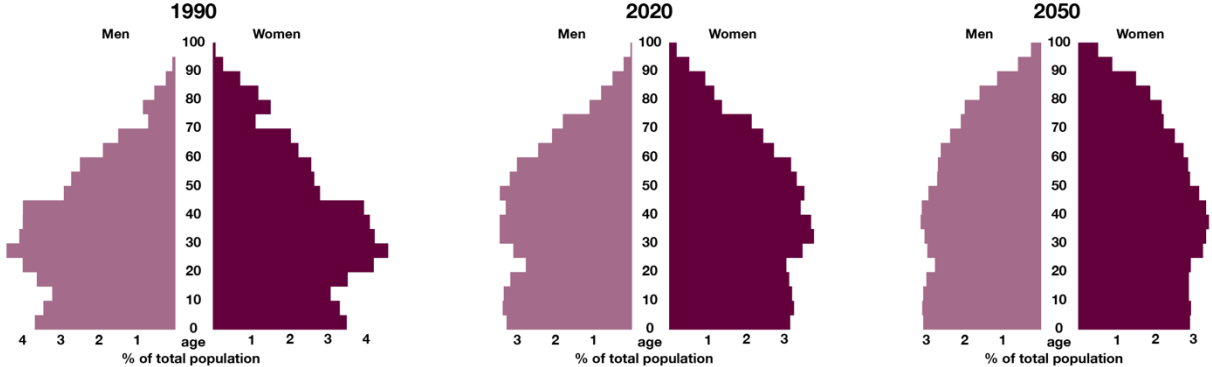


Figure 29: Population pyramids of IDF for 1990 and 2020, projected for 2050 (INSEE, 2017)

An increasingly ageing population can have widespread impacts on the system of urban mobility. The elderly have different requirements, preferences, expectations, and use patterns. Furthermore, an increasing demand for more accessible and age-appropriate solutions arise. While a more extreme ageing process is unlikely due to being the consequence of the current situation, a variety of developments can impact the system in other ways. For example, extreme shocks such as current pandemic can lead to decreasing life expectancies and change both growth and distribution. Further, a linear comparison between over 65-years-olds in 1990 and 2050 ignores that the improving healthcare also leads to different lifestyles. Hence, even if the ageing process remains this significant, its impact might be less strong due to longer active participation in the same activities as for example the age group of 50-65-year-olds.

This age distribution can be strongly changed through migration trends. France, and Paris in particular, is a global destination. Most migration takes place at the earlier

stage of life. If the current migration patterns change significantly, two possible consequences could arise. On the one hand, decreasing influx of younger people would further raise the average age. On the other hand, pulling factors such as eased immigration policies or pushing factors such as climate disasters or armed conflicts in other areas, primarily Francophone ones, could lead to another significant increase of the younger population brackets.

The accompanying distribution will also have significant impacts on household constellation, which have significant impact on movement patterns, mode sharing, and living choices and requirements. Currently, the number of marriages decreases, with proportionally high but decreasing divorce rates, and rising alternative household constellations. According to the OECD (2011), this combined with other trends could lead to up to 46% one-person households in 2030, a higher number than any other OECD country (which probably holds true for all other countries as well).

Hence, one possible extreme is an increasing individualisation or even partial isolation as result of the projected developments with widespread impacts on societal dynamics including birth rates, housing arrangements, or choice of transport modes. On the other hand, increasing cultural diversity resulting from increased immigration could reverse or alter current trends. Another possible trajectory is the renaissance of local networks and communities in urban areas. This new-found localisation and search for integration could lead to different but similar societal dynamics as traditional households. The simplest manifestation of this can be shared living, or service-based communal living concepts. This possible societal urban decentralisation, resulting community-based pathways as well as the arising need thereof, are largely discussed in literature (e.g., Rifkin, 2011) and found in current practices of urban planning and design, ranging from the 15-minute-city concept in Paris, to various neighbourhood strategies, localised public space and placemaking initiatives, and platforms to get to know, support, or exchange goods with neighbours.

Another key determinant is the socio-economic development, mostly in comparison to other areas. For this purpose, three levels are discussed: the global, regional, and local. For several centuries, Paris and its surrounding area constitute one of the leading global cities across domains and parameters (see among others, L'Institut Paris Region, 2019, Paris Region, 2020). It is unlikely that this will change within the timeframe considered for this project. Nevertheless, the development of global power dynamics will continue to shape its role.

Two major trends are possible. On the one hand, the Paris region can remain in a highly globally competitive position, being one of the leading metropolitan areas of the European Union and Europe in general. On the other hand, global powers can shift further towards Asia and Africa with growing economies, improving opportunities and quality of life. Depending on the scale thereof, Paris could become less attractive, which would lead to impacts on financial direct investments, global business location, and immigration.

On a regional level, two considerations are relevant. First, France has a highly centralistic setup, with Paris being at the core of the region, the country, as well as much of Western Europe. The dualistic organisation comes with local advantages as Paris is in the focus of developments, strategies, and investments. On the contrary, the divide between Paris and the remaining France can lead to increasing inequalities of access or political representation, among others. Such a trend could have manifold societal consequences, many of them potentially systemic.

On a smaller scale of the Paris region, the same disparity exists and may develop in different directions in the future. Traditionally, there has been a strong notion of ‘Paris and the rest.’ Over the last decades, various initiatives aimed at expanding the scope or providing counter poles, such as France’s national urban policy towards territorial equality, localised territorial policies, the Île-de-France (1961), Métropole du Grand Paris (MGP, 2016), unions of local administrations such as the CPS (2016) and others. In recent years further actions were initiated, including increasing investment in knowledge and business clusters outside of the city of Paris, integrating projects like the Grand Paris Express or the strategic choice of hosting the Olympic Games 2024 partially in Seine-Saint-Denis.

Again, two major trajectories are possible. Ambitions for decentralising and increasing territorial justice can be successful, leading to a smaller national and regional role of Paris and stronger attention and development in other areas. On the other hand, a continuous focus on Paris can retain the current dynamics and even scale them further with significant impacts nationally and locally. On the most local level, the same disparity exists. Fleury et al. (2013) studied spatial inequalities and their temporal trends and concluded that the inner-ring suburbs (mostly within today’s MGP) experienced growing segregation and polarisation, while the outer suburbs are increasingly less affected by poverty. They further identified two major spatial trends. First, gentrification takes place actively since 1990, with the *very well-off* and *well-off* municipalities decreasing in number but *fairly well-off* municipalities increasing rapidly. The latter constitute now more than 30% in the region, including large parts of the departments Yvelines, Val-d’Oise and Essonne.

The second trend is the ‘accentuation of social polarisation around two geographically clustered extremes, to the west and to the north of Paris’, leading to a ‘mutual spatial exclusion of the most socially specialised areas’ which comes together with a certain homogenisation within (Fleury et al., 2013).

The continuation of these developments could lead to even stronger local disparities, combined with spatial exclusion of low-income households. Gobillon et al. (2019) study this dynamic they call the *suburbanisation of poverty* further by examining homeownership policies and choices of the impacted households. Two mutually enabling tendencies they point out are the most frequent use of supporting policies for low-income households in areas with a more homogenous socio-economic population and less access to services and amenities, as well as the widespread lack of a ‘clear perception of the social and physical disconnections they would experience when they purchased their new homes’ (Gobillon et al. 2019). The two extremes in this regard would be most likely between a slight relaxation of current trends, yet continuing spatial inequality, on the positive side, and a near-dystopian intensification of spatial inequalities on the negative side, leading to a strong dual image of Paris and its environs.

Regarding the values and concerns of the people, the ‘Daily Mobility Barometer’ provides some interesting insights (Wimooov and Foundation Nicolas Hulot, 2020). The data shows that 89% of the surveyed population is worried about the environmental crisis, and 60% of the 18-24-year-olds believe that transport contributes ‘a lot’ to the climate damage. Nearly 60% favour an end of fossil-fuelled vehicles by 2040. 38% of car drivers anticipate reducing their use in next 10 years, while 50% can imagine buying an electric vehicle, even if the price remains higher. One out of two survey participants thinks that they could do parts or all of their trips by bike if the infrastructure would allow, while 55% think they do not have a choice how to move,

a number rising up to 85% in isolated communities. 77% of the same group also states that they have no access to public transport by foot. Additional to the overall accessibility, two barriers are showcased. For 50% of the participants, the cost of mobility is the primary barrier (paying an average of 90 euros in cities and 141 euros in countryside per month for transport), while psychological barriers exist as well. The apprehension of taking public transport affects over 29 % of the 18-24 years, as well as 25% of urban residents. Regarding the number and reason for trips, a disproportional negative effect on more deprived households was identified. While 1 out of 4 of that group state that they do not leave their home more often than 2-3 times per week, commuting to the job constitutes the reason for 43 % of the trips for the same group, while it is only 17% for the better-off groups (Wimooov and Foundation Nicolas Hulot, 2020).

5.1.1.2 Infrastructures of Paris

The social dynamics described in the prior section are shaped by and result in its spatial manifestation. Thus, understanding the various layers and hierarchies of a territory or metropolitan area is paramount as it shows which authorities are responsible for which developments, what public actors are involved, and whose interests come together or conflict.

While administrative boundaries should not define the scope of observation of urban mobility due to common mobility patterns spanning various scales, they are relevant as any use case of scenarios within public policy must adhere to the respective level of influence. Before we zoom in on the Île-de-France (IDF) and the inter-council partnership Paris-Saclay (CPS), an international perspective can provide various insight. First, Paris and its region are not independent but strongly connected globally and primarily in the Western European network (Figure 30).

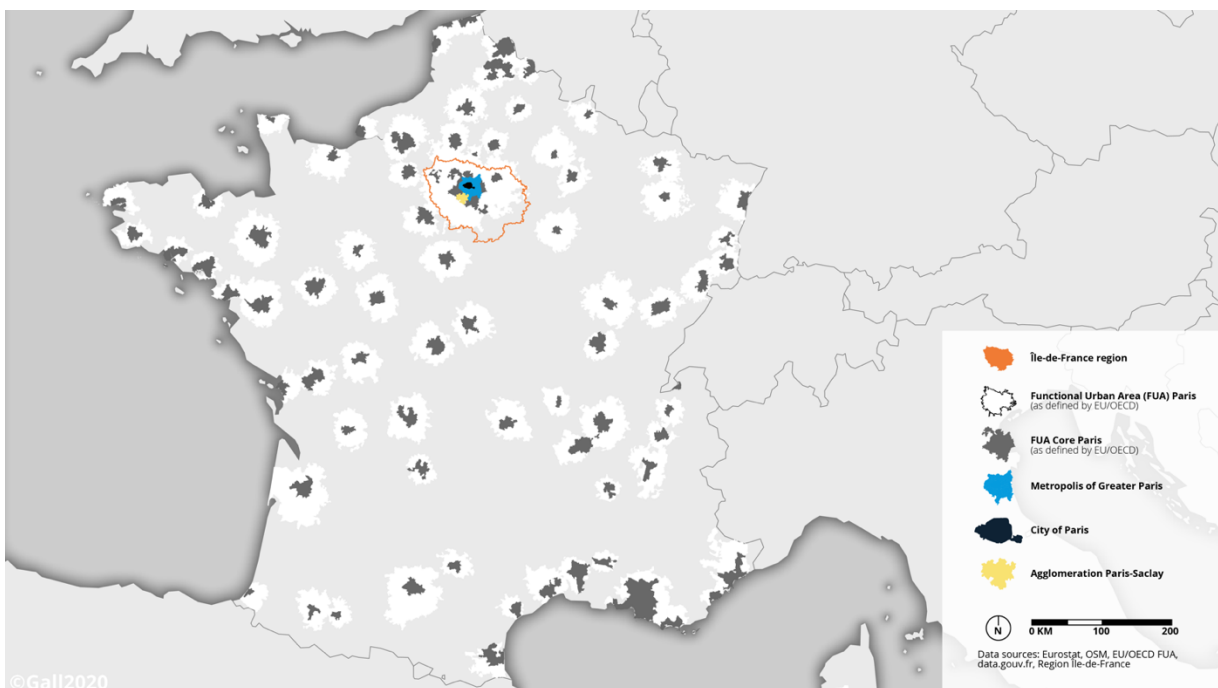


Figure 30: Functional Urban Areas of France

Networks of global cities are defining for the majority of today's economy, trade, finance markets, and more (L'Institut Paris Region, 2019), with Paris being one of the leading ones across categories (Paris Region, 2020) since nearly two millenia. On the other hand, the different layers of IDF, MGP, Ville de Paris and CPS are forming a

geographically clustered territory with strong direct interlinkages direct along the river Seine until the English Channel (and thus the UK), to secondary surrounding cities, as well as other international areas such as Brussels or Antwerp.

The IDF is constituted of eight departments, including Paris at the core (75), the inner ring of departments (92, 93, 94), and the outer ring (77, 78, 91, 95). This administrative region is however larger than the functional area and its core which are of primary concern for the research on urban mobility. The OECD in cooperation with the European Commission created a standardised, grid-based methodology to define these regardless of administrative or national boundaries. The result thereof can be seen for France in Figure 30, and the IDF in Figure 31. The white areas show the Function Urban Area (FUA), also referred to as commuting zone. This is defined as the continuous grid cells which are populated and from which at least 15% of the workforce commutes to the FUA core, reapplied on administrative sub-divisions. In case of overlapping commuting zones, the primary served FUA core is assigned. The FUA core, shown in dark grey, is the core city, defined as continuous 1*1 km grid cells with a population density of at least 1,500 inhabitants per square kilometre and at least 50,000 inhabitants in total (OECD, 2019).

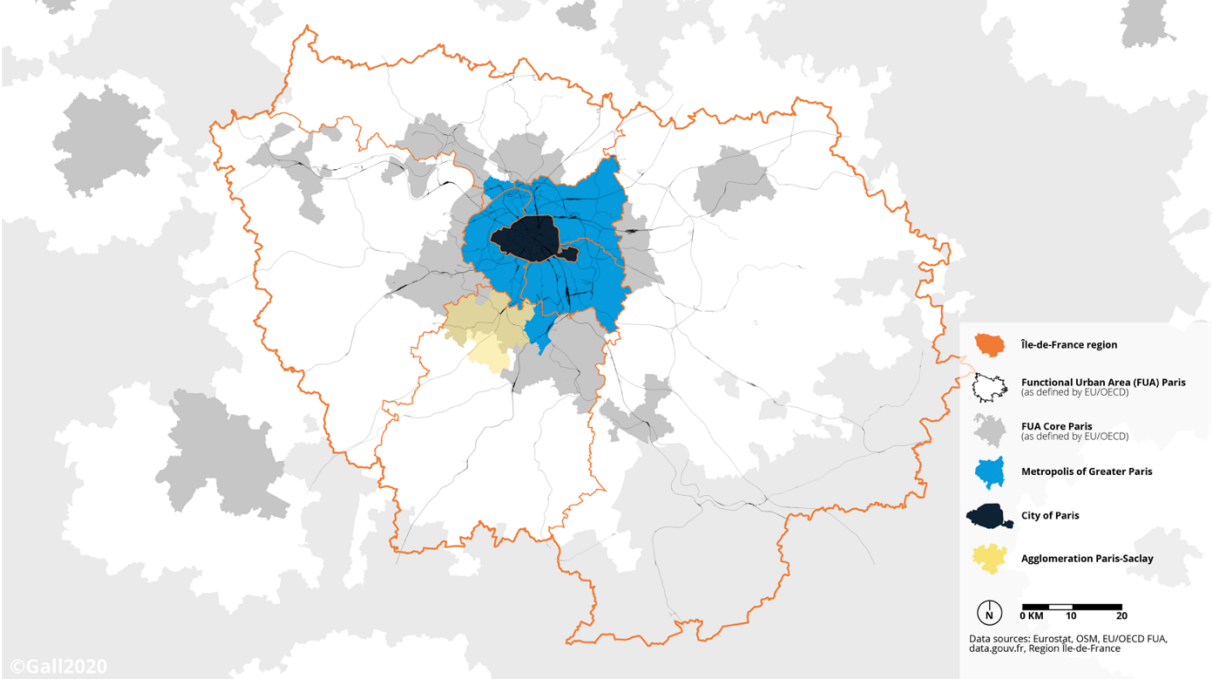


Figure 31: Administrative layers of IDF and CPS

This shows that there is a significant central FUA core spanning all departments of the IDF, as well as a few disconnected cores within the IDF and just outside. All of it is connected through an extensive commuting zone covering the majority of the region. Furthermore, three other layers are shown in the map above. In the centre is the City of Paris, portrayed in dark blue, equal to the traditional core, the city proper, as well as the department 75. However, despite its administrative boundary and the accompanying consequences, no actual separation exists in a spatio-functional sense. Furthermore, inner Paris combined with the previous inner ring departments (92, 93, 94) and a few municipalities just outside, forms the MGP, shown in light blue. Just outside in the south-west is the CPS, shown in yellow. The CPS shares its boundary in the north with the MGP and with the department boundary of Essonne (91) in the west. Furthermore, its majority lies within the FUA core, while its north-eastern corner falls into the outer commuting area.

These different administrative and functional layers are important for a couple of reasons. First, policies and services related to mobility can change depending on their department. A simple example are the zones of public transport in the Paris region. Organised in six concentric circles, each transport zone has implications on prices and abonnements. The city of Paris is primarily the central zone 1, zones 2 and 3 are the three surrounding departments (92, 93, 94) which constitute together with Paris the GMP, zone 4 includes most of the FUA core, as well as the majority of the CPS, while zones 5 and 6 include further destinations, including, for example, the airport Charles de Gaulle. Other mobility-related differences are the responsible public transport providers, suitable navigation apps, micromobility providers, among others.

Simultaneously, these boundaries do not matter much for mobility patterns, trips, daily commuting and many other dimensions of urban mobility. No part within the FUA of Paris is independent and allows for a separate consideration of mobility within, neither in the central city of Paris, nor in the CPS. In a polycentric region or 'urban village' model (based on Alain Bertrauds' classifications of spatial structures; 2008, in Bertraud, 2018), this could be possible if the boundary behaviour is incorporated. Polycentric (or dispersed) regions consist of several, seemingly equal cities or cores which jointly constitute a system which has a stronger role than its independent parts combined due to, for example, agglomeration economies. The Dutch Randstad (Amsterdam, Rotterdam, The Hague, Utrecht) or the German Ruhrgebiet (Dortmund, Essen, Duisburg, Bochum) are regional examples, while many Asian regions such as the Pearl River Delta utilise the same principle. Paris, however, remains a foremost classical monocentric region (with trends/ambitions towards a composite model). Currently, the IDF region has a clear hierarchy of a central core (city of Paris), as well as sub-centres and exterior centres which serve and depend highly on the core. While an issue too contested issue to develop here, the establishment of the MGP might even contribute to the monocentric structure, even if it is accompanied by actions to decentralise and distribute.

A glimpse into the past can explain its structures and elements today and provide a foundation for future trends. With a history of over 2,000 years, a complex and interconnected system evolved which rose to a world leading position and led to the IDF becoming the home for over 12 million people. The section intends by no means to provide a full historical description of Paris and its environs. Instead, a few elements deemed relevant for the purpose of the Chair's work and urban mobility futures are chosen and presented in the following three sections of Early History, the Haussmann Plan, and Post-World War II, feeding into the description of the present status.

Walled history

Starting as a small settlement on/along the Seine (probably today's Île de la Cité) a few decades BC, the settlement grew continuously, was renamed to Paris in the fourth century, and grew into one of Europe's most populous and influential cities in the early medieval times. The associated power and resources led to various internal and external struggles and several occupations over the years. To defend its position, Paris was enclosed by a wall for most of its history starting from the Gallo-Roman empire and until 1929. The different positions defined the shape and growth of Paris by containing most of its growth within and shaping street layouts. Walls or any kind of physical enclosure have a significant impact on the development of a city. While an area is closed, there is a clear concentration of growth and distinction between the safe inside and the less controlled and unsafe outside. Hence, enclosures contribute to the densification, as well as keeping sprawling peripheral development to a

minimum; in particular farms and smaller, serving villages. With the destruction of the last wall, space was freed up which allowed for a range of large-scale projects and the much-contested ring road 'Boulevard Périphérique' demarcating the interface of the city of Paris (dep. 75) and the surrounding until today.

Hausmann Plan

In the 19th and 20th century, Paris population exploded. Industrialisation, epidemics, lacking sanitation, among other factors, led to widespread concerns of pollution and needs for new housing developments. These concerns, as well as intentions to better represent the city, resulted in the commissioning of Georges-Eugène Haussmann by then-emperor Napoleon III to renovate the city, in particular to restructure and modernise Paris. This led to an often criticised but also highly celebrated transformation to the architecturally coherent image, as well as spacious boulevards and cultural institutions. As part of the transformation, existing structures and links were assessed, and new supporting infrastructure and roads implemented, superimposing a new spatial structuring layer on the previously organic settlement. Many of the implemented transformations were inspired by London, primarily in the sector of sanitation. Also, the first metro in London started its operation in the 1890s, which Paris followed some years later in 1900. At the same time, Ebenezer Howard presented his Garden City concept as a response to the city becoming too polluted and dirty. New mobility modes arose to connect more distant regions. Hence, he proposed to divide the living areas from the functional areas. Combined with the disappearing walls and defence systems, this marked the start of rapid spatial expansion and sprawl. While the boulevards and scale were over-dimensioned for the transport needs during the preparation phase of the plan (pre-car) they provided a welcome space for large scales transport arteries without the need of demolishing the built environment, defining today's mobility axes within Paris, as well as the connection with the outside.

Post-World War 2

With little to no significant destruction during World War II, the post-war period led to accelerating growth, progress, and development. A variety of plans (regional, district, local development plans) were developed as tools to address new challenges, and large developments were planned or continued outside and inside the traditional city boundaries, strongly defined by modernist concepts. At the same time, the growth and importance of cars continued, with more streets built, the completion of the ring road, sub-urban sprawl, integration of surrounding towns and villages, among other trends. Simultaneously, a global trend intensified. Instead of locating work, life, and leisure in one small area, it became increasingly separated. Both enabled by new, faster, and more convenient mobility solutions, as well as strengthening the mobility sector due to increasing demand. The global era of suburbia started, in the case of Paris complemented by large scale (social/public) housing developments. While modernist tendencies initially proposed to make way for the future by fundamentally different and new plans (cf. Plan Voisin by Le Corbusier), conservative and more context-responsive strategies quickly followed to preserve the existing quality of Paris, both architecturally as well as structurally. On the other hand, the increasing availabilities of cars and limited housing stock in the city intensified the sprawl and incorporation of smaller villages and town, for example in CPS, even more so after the expansion of the Regional Express Network (RER) B line through the integration of the preceding train line 'ligne de sceaux'.

Inter-council partnership Paris-Saclay (CPS)

The CPS is an administrative union of 27 communes in the department Essonne (91) just south of the MGP, with a population of over 300,000. It was founded in 2016, emerging from the preceding inter-council partnership of the Saclay Plateau and the inter-council partnership Europ’Esonne, as well as incorporating two additional communes. It borders the MGP in the north and has a transport axis (today’s RER B) in its central valley, as well as a part of the RER from the west to the east. Furthermore, Massy as the central mobility hub within CPS has a high-speed railway (TGV) station.

The CPS as an administrative body is working across fields such as smart city, mobility, open data provision, employment and other inter-commune projects. Further, CPS and its area is an experimentation field of novel mobility solutions, as well as the improvement of existing services (e.g., through enabling multimodal exchange on RER B stations to bikes), strengthened through the density of research and tertiary education providers on the Saclay Plateau. Distinct in the CPS is the terrain of a northern and southern plateau (Figure 32) with a valley in the centre which accommodates the RER B line, as well as most of the built-up area additional to the biggest commune of Massy in the east. The plateau Paris-Saclay lies on its northern side, introduced earlier as one of the major projects and urban development sites of the IDF, and is one of the clusters for education and research and will undergo major transformations in the coming years, accelerated through the expected connection to the metro network as part of Grand Paris Express. Les Ulis, a new town development from the 1960-1970s and an industrial park are situated on the southern plateau, mostly contained by the highway A10, or L’Aquitaine, in the Southeast.

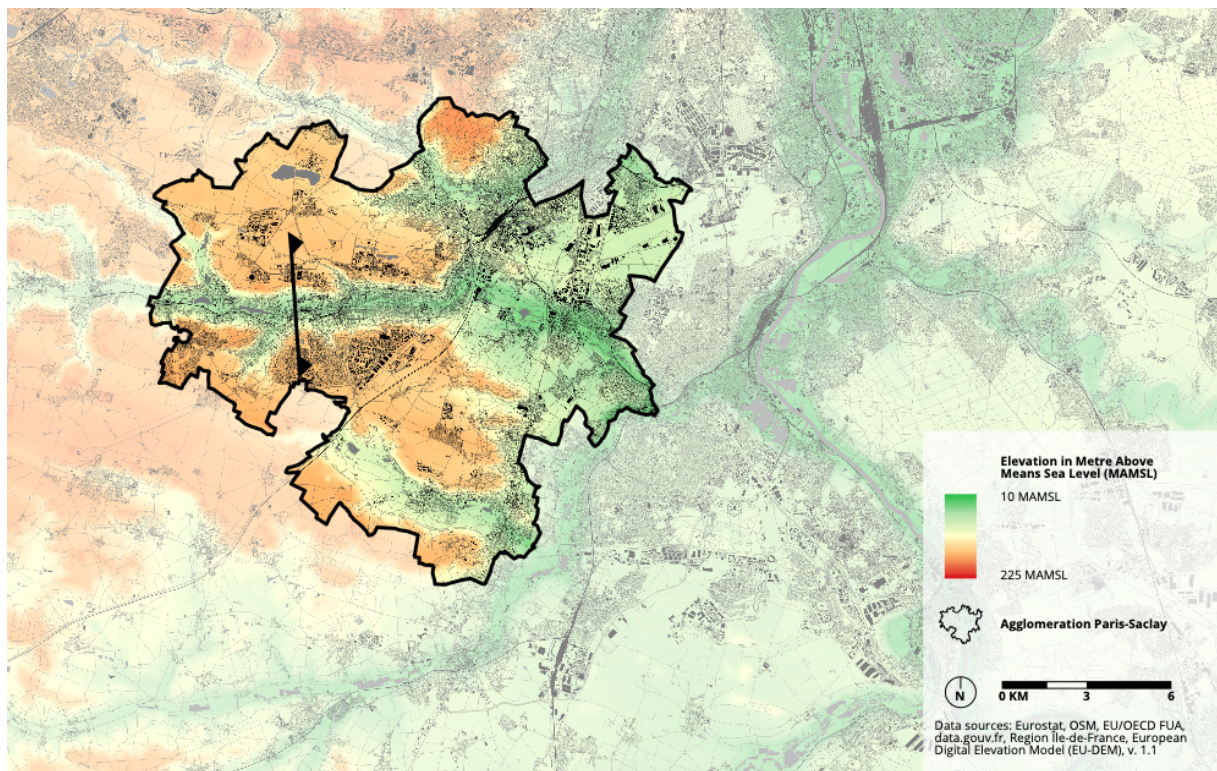


Figure 32: Geographical terrain of CPS

While the majority of Paris is relatively flat, the plateaus’ edges constitute a boundary or barrier for mobility. Their development increases the number of daily commuter numbers which are, however, limited by currently discontinuous public transport access, even despite their proximity to the existing RER B line (Figure 33SectionCPS).

The challenging access to the plateau with continuously increasing number of commuters and lack of bus drivers on regional level lead to regular negative press and increasing pressure on local and public transport authorities.¹⁹

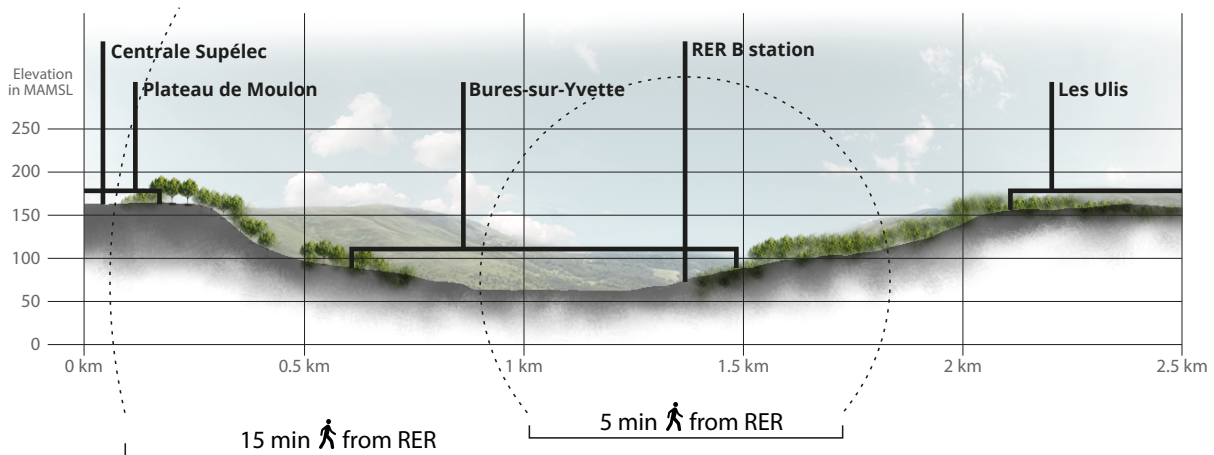


Figure 33: Section of CPS valley showing walkability (based on Google Earth/OSM data; CC BY 4.0)

The possible socio-demographic and -economic developments described in the previous section could each have a significant impact on the spatial environment, thus the movement within. Referring back to the historical snapshot of Paris and a 200-year growth simulation²⁰, a few observations can be made. First, the IDF has become a continuous and widespread metropolitan area of built-up land which is highly centric and grew rapidly along major axes. Natural axes are for example the river Seine, or valleys between hills and plateaus such as the CPS. Human-made axes are primarily the transportation lines, which are widely responsive to natural axes. Additionally, the growth centres defined in an earlier map in the greater Paris area are defining current growth and planned projects.

Depending on the demographic changes, different spatial extremes are possible. The continuing development along mobility axes and around set clusters (such as the Saclay plateau) could continue in a relaxed pace. On the other hand, de-urbanisation due to increasing teleworking and a rural renaissance, a housing market bubble, or localised shocks can lead to de-growth and widespread vacancy, among others. Further, again accelerating urbanisation and significant growth could result from change of spatial and territorial policies, increasing immigration or similar, and would lead to a growth going further than current territorial planning strategies are prepared for.

Lastly, a significant impact factor regardless of trajectory is the density development and average housing unit size and household preference, with widespread impact on the mobility system. Two extremes can delineate the possible. On the one hand, decreasing household sizes, service-based housing models, and localising communities can lead to a highly densified, multi-functional polycentric network of nodes, limiting most sprawl or spatial expansion inside the current boundaries. On the other hand, teleworking, increasing mobility (e.g., due autonomous vehicles), and

¹⁹ <https://www.cnews.fr/france/2022-09-20/essonne-lenfer-des-usagers-pour-aller-et-venir-luniversite-de-paris-saclay-1268438> [accessed 30 July 2023]

²⁰ https://youtu.be/9ieL0A_icK0 [accessed 23 July 2023]

changing need profiles (e.g., separated working space/studio, individual garden) can lead to further sprawl and a widespread expansion of the area of IDF far beyond its current spatial scope. CPS being at the interface between rural and urban – metropolitan hinterland and a TOD-induced linear development cluster – will be significantly impacted by these developments. *Scenarios could hence explore the impact of urban mobility on a dissolving, stagnant, densifying, or sprawling CPS and vice versa, as well as paying attention to contrasting spatial developments within each.*

As the above already hinted towards, the housing markets are an important factor for a variety of spatial and social dynamics. Paris' role as a global centre comes with high, but relatively stable real estate values. Looking into possible futures includes looking into *why* people will live *how, where*. Another arising need is to redefine roles of urban areas if the role as habitat for access to opportunity vanishes due to teleworking and decentralisation. The report 'Habiter dans 20 ans' of the Paris-based think tank Terra Nova (2019) provides a quite comprehensive overview over national and regional trends. The report points towards an expected growth in sub-urban areas, existing villages and small towns, strongly linked to access and transport axes towards large cities. Without repeating previous considerations of impacts of urbanisation, housing models or demographic changes, the added point in regard to housing shall focus on the type of housing stock which will cater for this growth. The growth can manifest in traditional sub-urbanisation and sprawl, or high-density polycentric growth. Both have significant impacts on mobility systems and can be enabled or prevented by the same.

5.1.1.3 Mobility services of Paris

Mobility services are the dynamic link between people and the built environment and infrastructures. Before zooming in on actual modes of mobility, we first outline from where-to-where people move by introducing the density of activities and locations. The IDF is an international centre of research and higher education and home to 1,166,000 companies, creating a total of 6.4 million jobs (Paris Region, 2020). Within the IDF are a total of 5.7 million housing units.

Further, the IDF is home to a variety of cultural amenities, about 4,000 historic monuments, 239 shopping centres, as well as 23,000 restaurants and over 150,000 hotel beds, constituting some of the strongest sectors of commerce and hospitality in the world (Paris Region, 2020). The combined impact of this leads to about 108 million annual passengers of air traffic in three international airports with over 700,000 aircraft movements. Further, there are 19 million train passengers coming in through one of the seven high-speed train (TGV) stations, a total of over 50 million tourists, including 22.2 million foreign ones.

Additional to the high-speed train stations, there are ten normal train stations, which serve combined with the TGV 1 million passengers on 3,550 trains per day. Five of the ten railway stations reach over 100,000 travellers daily. The Gare du Nord is the busiest European train station. Per year, 19 million TGV passengers are travelling from Paris to main European destinations through railway network in the IDF (Paris Region, 2020). 6,200 regional trains cross the region every day with over 650 trains simultaneously at rush hour (Paris Region, 2020).

A variety of self-service and free-floating bikes, cars and mopeds exist, which lead to 850,000 trips per day, a 30% increase since 2010. 40% of these trips during the week are the work commute. Just the Velib Metropole itself, the public bike sharing service of Paris since 2007, has about 16,000 bikes, 30% thereof electric power-assisted

bicycles, facilitating around 70,000 trips per day. Véligo Location, a long-term rental service of electrically assisted bikes, provides another 10,000 bikes (Paris Region, 2020). Lastly, in the city of Paris, around 18,000 e-scooters, 8,500 other bikes, and 4,000 scooters complement the mobility options, combined provided by various operators). Within 12 months, the free-floating scooters alone have been used for a total of 18,5 million trips, covering 41,4 million kilometres with an average trip distance of 2,2 kilometres (APUR, 2020). In 2023, a public vote has led to the planned ban of free-floating scooters, assumed to put a strain on shared micro-mobility development in Paris and other European cities which might follow suit (Paris, 2023). Annex AN.6.1 contains Tables 6 to 11 which show the current situation as well as developments since 1976 of selected mobility-related indicators based on public transport surveys, including the motorisation rate, modal shares, and number and type of trips.

They can be summarised in three points. First and foremost, the urban mobility system of the Paris region is very extensive and highly complex. Second, *a few major trends exist, including increasing number of cars, increasing number and duration of trips, as well as an increase in active mobility and public transport, and decrease of trips done by car.* Third, new modes and providers are constantly and with an increasing pace challenging the status quo and have already today a significant impact on the mobility services, mostly in inner Paris.

To respond to these developments and the pressures to render Paris more sustainable, Paris' administration has pushed for a range of green policies over the last years, including reducing parking lots in the city, subsidising the purchase of electric bicycles, opening school streets only to active mobility, or most recently integrating the 15-minute city into the city agenda. Referring to the ring road, a variety of competitions and initiatives for transformative urban interventions have been launched over the last years, including Réinventer Paris by the city of Paris which put the reimagining of the areas of the ring road in focus. Long preceding campaigning for better cycling integration, the re-election of Anne Hidalgo, as well as the changing mobility patterns during the COVID-19 pandemic and resulting temporary cycle lanes, provides a highly enabling environment for the strengthening of active modes of mobility. However, as observations of activity maps in the Paris region show, the network is currently very disconnected. While some axes as well as the paths along the Seine are dominant and continuous, many other parts consist primarily of discontinuous patches. An initiative by the Collectif Vélo IDF conceptualised and lobbied heavily for a regional approach to continuous cycle lanes by proposing the RER V (vélo), inspired by the public transport network.²¹ While a variety of cycle network upgrading works are underway across departments, the modal share of bikes compared to other European countries is still relatively low, even more so in the case of intermodal mobility. While in the Netherlands about 40% of train commutes are either started and/or ended by bike, in the IDF, less than 2% commutes combine cycling and public transport (L'Institut Paris Region, 2020).

Moving on to a short outlook on already started or planned projects which will impact the urban mobility futures, two major developments are noteworthy. On the one hand is the Grand Paris Express which adds 200 kilometres of automated lines and 68 new stations to the metro network. Instead of the currently prevailing star-shaped and centric shape of metro lines, the network extension takes primarily place outside of

²¹ <https://rev.fr> [accessed 23 July 2023]

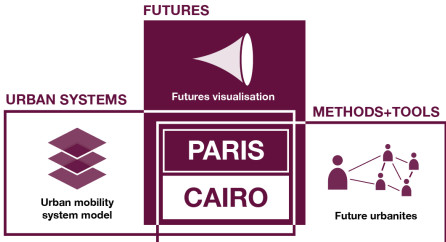
Paris proper and connects different clusters and sub-cores through three overlapping circular lines (Société du Grand Paris, 2020, Paris Region, 2020). The new lines shall allow for 2 million passengers every day and result in a total of 35 billion euros invested until 2030, with one million square metres of associated construction (Paris Region, 2020). The Grand Paris Express will link the three airports, various business districts and scientific clusters. The areas of interest include two locations of the Olympic Games 2024 which come with widespread developments and investments.

A strategic choice was made as part of the bid to host the games in two primary locations (except special locations dispersed as far as Tahiti). Additional to central locations, for example along the Seine or between Eiffel Tower and École Militaire, an area in the department Seine-Saint-Denis (93), in particular the three communes Saint-Denis, Ile Saint-Denis and Saint-Ouen, will accommodate the Olympic Village, as well as training and competition sites. Additional to the overall impact on tourism, investment, and large-scale developments, the clear targeting of the Olympic Games 2024 on an area outside the city centre as well as its conceptualisation as a tool for social policies and programmes is significant. Strategies for social-driven repurposing of Olympic sites after the games show the widening focus on – at least – the area of the MGP, and can directly inform short- to medium-term futures, as well as act as a platform for further campaigns towards sustainable practices and innovation. While Massy-Palaiseau and Paris-Saclay are shown as secondary and main centres with accompanying major urban projects of the CPS, supposedly to be connected by the new metro network, they do not contain any of the Olympic sites and will hence primarily be impacted indirectly.

Lastly, a short discussion of defining boundaries of possible future mobility shall conclude this case study introduction. While the respective extreme development of each of the above topics would have a strong influence on mobility (and vice versa), defining the boundaries of future mobility is challenging. A further increase of cyclists and pedestrians and reduction of private cars in central Paris, as well as an increase of the latter in outer areas is likely (Ville de Paris, 2019) due to existing barriers within Paris of density, available space and current policies. Even a major political shift in the medium-term future would most likely not alter this trend significantly. The situation in the outer areas is very different. A delineation is nearly impossible due to a variety of unknown factors.

Possible mobility futures in areas such as CPS are more likely defined by very uncertain parameters as discussed in the previous sections, the supply, demand and people’s choices of mobility than by pre-defined limits. Major boundaries for this are primarily the geographical ones, as well as the long-term orientation along the RER B line and the new metro line. Furthermore, technologies may have a widespread influence.

5.1.2 Localisation of scenarios in Paris



The literature review showed that many approaches exist for creating scenarios. However, gaps were identified regarding the reuse and localisation or spatialisation of scenarios.

This section is dedicated to this process and presents the method developed in and applied to Paris. The section consists of three parts.

First, we introduce a developed checklist to facilitate the reuse of existing scenarios. Next, we discuss a set of workshops which were conducted to localise scenarios, resulting in an approach centred on archetypical scenarios and intermediary design objects, such as personas. Finally, we apply the approach to Paris and present the resulting scenarios which feed into the subsequent chapters.

Checklist to evaluate quality of scenarios

Creating scenarios is a resource-intensive process which constitutes a barrier to broader adoption. On the other hand, research has shown that most scenario sets follow the same patterns and resulting scenarios can be simplified as archetypical scenarios (Dator, 2019; Fergnani and Song, 2020). Miskolczi et al. (2021) analysed a set of urban mobility scenarios until 2030 which resulted in a set of four scenarios. However, when either choosing to work with existing or such archetypical scenarios, it is important to be able to decide if they are suitable for their purpose. As detailed in Gall et al. (2023), we created a checklist via expert interviews and a workshop as a part of a student project by Malek Ben Ammar. This resulted in 25 question-like formulated indicators, organised in the four categories Process, Attributes, Content, and Representation (Table 6).

Table 6: Checklist to guide designers and decision makers in verifying if existing scenario sets or archetypical scenarios are suitable (I = individual scenario, S = scenario set)

	I/S	Quality Indicator/Reference	IV	WS	LT
Process	S	Are the required resources to transform this set of scenarios clear and acceptable?		X	
	S	Is the process of the creation known and sound?	X		
	S	Are the participants and their roles that were involved in the process clear? Do they ensure sufficient diversity?		X	
Characteristics	S	Is the number of scenarios adequate for the purpose (neither 2, 3, uneven numbers, or too many)?	X	X	
	S	Is there a specific timeframe assigned to the scenarios? If yes, does it correspond with the project's needs?		X	
	S	Were the scenarios created for a specific location? If yes, does it correspond with the project's needs?		X	
	S	Do the scenarios provide meaningful alternatives to each other? (Spaniol and Rowland, 2018)			X
	S	Is there no strong distinction between preferred and nonpreferred/utopia vs. dystopia?			
	S	Are they temporally rooted in the future? (Spaniol and Rowland, 2018)			X
Content	I	Are all scenarios concerned with the same issues/challenges?			X
	I	Is the scenario coherent? Can the events described be presented as a whole? (Chermack, 2006)			X
	I	Are the scenarios plausible and possible?	X		
	I	Is each scenario interesting? (Chermack, 2006)			X
	I	Is the information provided by the scenario relevant for those who use it? (Chermack, 2006)		X	X
	I	Does it combine qualitative and quantitative information?		X	
	S	Are the scenarios meaningful alternatives (Spaniol and Rowland, 2018) and distinct (Chermack, 2006)?			X
	I	Is the story challenging? Does it make you think differently?		X	
	I	Do we have information on the pathway between today and futures?			X
I	Is the scenario comprehensible?	X			
Representation	I	Does each scenario have a catchy, coherent, and descriptive name?		X	
	I	Is it possible to relate to the scenarios (Chermack, 2006; Vallet et al., 2020)?			X
	I	Is it communicated with an interesting story and/or narrative? (Spaniol and Rowland, 2018)		X	
	I	Does it (allow to) integrate specific elements, places, and details relevant to the user?		X	
	I	Is it easy and effective to communicate in a supervised and unsupervised setting?			
	I	Are the intermediary design objects adapted to the target audience?		X	
	I	Does it provide the required types of cross-media formats, e.g., graphics, text?		X	X

Based on these questions, we can select existing scenarios. In the case of Paris, we decided to choose to work with the archetypical scenarios created by Miskolczi et al. (2021) as they fulfilled most of our criteria will permitting to be extended with additional data where necessary.

Localisation of scenarios

The next challenge is to adapt such scenarios to the local context of the UMS of Paris. This holds true both for archetypical scenarios as well as most scenarios created by public or private entities as they are usually created on a national or global scale but rarely contain local information or geographical context. We organised seven workshops in which we tried different methods to achieve this (descriptions in Annex AN.3. The workshops included online and offline workshops conducted in the closed setting of the Anthropolis Chair or publicly, for example, as a special session at the 2022 ISOCARP World Planning Congress. A few principles arose:

1. The created futures cone (see Chapter 4.2) proved respectively useful to quickly communicate key concepts and terminology of futures studies.
2. The dual concept of trends (future development assumed to hold true for all scenarios) and uncertainties (future development with high impact but low certainty) permits to discuss in collaborative settings what are key elements to be integrated. In the workshop in Cairo (see Annex AN.3.9), a comparative test was organised to see if participants find it easier to start with uncertainties or with spatial development. It appears as a dual approach starting with spatial developments and then iteratively attempting to formulate and refine principal uncertainties, is most intuitive.
3. High-quality and suitable existing scenarios permit to immerse the workshop participants in the alternative futures and thus enable them to imagine how different developments, e.g., the public transport supply, might look like in a specific scenario.
4. Personas as a second archetypical representation permit a more people-oriented discussion and elaboration on, for example, where what type of people might live predominantly in the future or what profiles will be more or less frequent.
5. Finally, the gamified use of maps, figures, and icons – even if just used sparsely – has suggested the potential benefit of the same and permitted to enable a discussion between participants. This includes, for example, icons indicating an increase of residential developments in one area or another.

While the above elements could address some arising challenges, a number of limitations and challenges remain. A critical one is that mostly people highly aware of local plans and visions are not able or willing to put them aside. Paraphrasing a workshop participant, *the creation of spatial scenarios is not necessary as we have the master plans which show what will be build where and when*. This is neither the ambition of master plans, nor have middle- to long-term urban plans a successful track record in being realised (cf. Goodspeed, 2020; Bertraud, 2018).

Another challenge, mostly identified when working with urban planners and designers, is the prioritisation of exploratory over normative approaches. While planners are very used to working with spatial plans, the tendency is to quickly choose which is the scenario perceived as ‘good’ and ‘bad’ and then let them evolve into utopian and dystopian options.

Aside from these challenges, an approach starting with carefully selected existing or archetypical scenarios, followed by defining local trends and uncertainties and a

range of intermediary design objects such as personas, permits to collaboratively localise scenarios with a set of diverse local and subject matter experts.

Scenarios for Paris

Compared to the structured localisation of scenarios for Cairo which will be presented in one of the subsequent sections, the process for Paris contained a large range of discussion, interviews, workshops, and other elaborations and cannot be present as a straight-forward process. Nevertheless, utile scenarios resulted which we briefly describe here. We chose to work with a set of archetypical scenarios due to a matching timeframe (i.e., 2030) and the most comprehensive integration of various urban mobility trends and uncertainties. The set has been created by Miskolczi et al. (2021) and results from a conducted systematic literature review of urban mobility scenarios for 2030. The four scenarios are listed below:

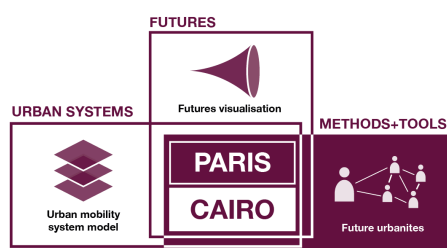
1. Grumpy old transport (continuation of current system)
2. At an easy pace (continuation of current active mobility and sharing trends)
3. Mine is yours (decreasing private ownership and increasing servitisation)
4. Tech-eager mobility (techno-push futures, including AVs and EVs)

Localised in the context of Paris and combined with trends and uncertain developments discussed in the case study description, this results in the trends of future urban development, *slight increasing urbanisation mostly in peri-urban areas, ageing, and ongoing population growth.*

Spatially, the main uncertainties are the locations where people will live and work. Findings collected via the conducted workshops are integrated in the method described in the subsequent section. Regarding the mobility system, the critical identified uncertainties are what modes will be available where and what type of users exist in what quantities. A specific and defining element is, for example, if people will have or prefer using cars.

For the following application, we decided to integrate *trends for the population and the mobility service while integrating uncertainties regarding people choices and their location, as well as the location of their workplaces and other activities.* Further developments integrating dynamic land use and transport interactions are outside of this work's scope but envisaged as future works (cf. Pucci, 2021; Ariza-Álvarez, 2021a-b, 2023). Our focus in the next section is on the first layer of UMS: Future urbanites.

5.1.3 Application of scenario-based method in Paris



This sub-chapter presents a method to improve the ability to design future urban mobility systems by integrating different approaches for modelling what the future could be and who could be the users.

The proposed scenario-based design and personas allows to *create data-driven proto-personas* – a set of archetypical users with assigned characteristics

and behaviours – test their validity, *derive distributions across geographical areas, and transform them for different 2030 scenarios.* This serves as input to create full personas and synthetic populations as intermediary design objects for the *collaboration of designers and simulation experts.*

The methodology is applied in the context of Paris. It contributes to urban mobility solution design that is more aware of future uncertainty and diverse needs of users, therefore, better capable to respond to today’s challenges.

Availability of data and material

Used data is open access and available via the information provided in the references. Data files of the output as well as all files used for the data analysis and transformation are available as commented files online:

<https://github.com/TjarkGall/proto-persona-clustering>

The method starts with building and validating a set of *proto-personas* (PPs) based on census data and mobility surveys for the present (Step 1-5, Figure 34). PPs are defined as a pre-stage for personas. They contain a set of quantitative information that are archetypical for mobility behaviours of a part of the population (Gall et al., 2023b). In the process, PPs are created independently of age and area to create personas that can be used across age groups and living locations. Steps 6-8 compile *trends and uncertainties* and match them with scenarios, followed by a *proportional redistribution of PPs* (Step 9). Lastly, the focus is on transforming the generated data into design objects for qualitative and quantitative approaches, here personas and synthetic populations (Step 10). Figure 34 shows the steps, including the methods and tools used for each step, and the input data. The core steps of the method are fully reproducible with open data and a public repository. In the next part, each step is described in detail. Intermediary results are shown throughout, while final outputs are in the results section.

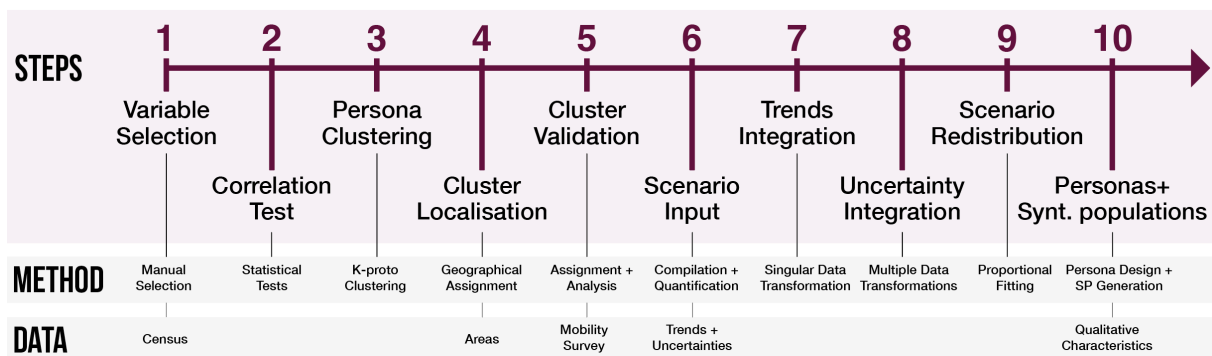


Figure 34: Combined development process of data-driven personas and synthetic populations for future scenarios (based on Gall et al., 2023d)

Step 1: Choosing cluster attributes

Three categories of census data attributes are selected from the available ones: 1) Attributes for clustering (e.g., household size), 2) Attributes for categorisation (i.e., age, area), 3) Attributes to supplement PPs. For the selection of variables, three considerations are important. Some variables can be categorised based on literature or inherent requirements of the process. Second, subjective choices inform the clustering in the context of mobility behaviours and preferences. Third, a verification for partial dependence of several variables supports the choice of most suitable variables. 25 variables are the basis for the following data preparation and clustering (Table 7).

Table 7: Census information chosen for clustering (translated by author; see Annex AN.6, Table 51 for codes from the 2019 Census. Descriptive statistics are provided in Annex AN.6, Table 52 to Table 54; Gall et al., 2023d)

I/H	Code	Description	Type	Use
Characteristics for categorisation				
I	AGED	Detailed age	Numerical	Category
H	AREA	Primary residence area	Categorical	Category
Household values				
H	NBPI	Number of rooms in the accommodation	Numerical	Cluster
H	NE5FR	Number of children aged 5 or under in the family (combined)	Numerical	Cluster
H	NE17FR	Number of children aged 17 or under in the family (combined)	Numerical	Reference
H	NPERR	Number of people in household	Numerical	Cluster
H	GARL	Reserved parking space	Categorical	Cluster
H	NA17	Economic activity in 17 positions	Categorical	Cluster
H	STOCD	Detailed housing occupancy status	Categorical	Cluster
H	TRANS	Main mode of transportation most often used to get to work	Categorical	Cluster
H	VOIT	Number of household cars	Numerical	Cluster
H	TYPL	Type of construction	Categorical	Cluster
H	SURF	Living area of residence	Ordinal	Cluster
Individual values				
I	COUPLE	Declaration of life as a couple	Dichotomous	Cluster
I	CS1	Socio-professional category in 8 positions	Categorical	Cluster
I	DIPL	Highest degree	Categorical	Cluster
I	ETUD	Registration in an educational institution	Dichotomous	Cluster
I	ILETUD	Study location	Categorical	Cluster
I	ILT	Work location	Categorical	Cluster
I	IMMI	Immigration status	Dichotomous	Cluster
I	INAI	Birthplace	Categorical	Cluster
I	MOCO	Way of living together	Categorical	Cluster
I	MODV	Way of life	Categorical	Cluster
I	SEXE	Gender	Dichotomous	Cluster
I	STAT_CONJ	Marital status	Categorical	Cluster
I	STATR	Grouped professional status	Categorical	Cluster
I	TACT	Activity type	Categorical	Cluster
I	TP	Working time	Categorical	Cluster

Step 2: Data preparation

The selected attributes are organised, their data types transformed, and individual entries scaled stochastically by their statistical weight to a total of nearly 14 M individuals. To account for the geographical focus and mobility flows between the

focus area CPS and its surroundings, geographical codes are assigned for each record.

To avoid overrepresentation and complexification, a statistical analysis is performed to test for correlations between numerical variables aiming to reduce the number of attributes if some of them are significantly correlated. Statistically significant ($p < 0.05$) and high degree correlations exist between the number of children under 17 (NE17FR) on the one side and children under five (NE5FR) as well as household size (NPRR) on the other. Consequently, NE17FR is excluded from the clustering. For the remaining combinations, no variable can be identified which explains another variable strongly enough that exclusion would be justified.

Step 3: Proto-persona (PP) clustering

Next, census entries are clustered based on selected attributes. The mix of categorical (e.g., socio-professional category) and numerical information (e.g., number of cars) excludes common clustering approaches. The k-prototype method is used which was developed to cluster including categorical data (Szepannek, 2018). The method searches most suitable central values for a set number of clusters. These central values are adapted over n iterations to improve the model fit. The quality of the outcome can be defined by the distance between the values assigned to each cluster and the central values. For example, if the number of cars per household of one cluster is one but some data entries with two cars are still assigned to the cluster due to a high fit in other categories, this difference is defined as distance to be minimised.

To cluster, the number of clusters is defined. This can either be a subjective choice or the result of a preceding test. For the latter, a scree-test can be performed (Szepannek, 2018). The objective function is made up from the 'within-ness'; the 'sum over all clusters within distances to the prototypes for each cluster' (Szepannek, 2018, p. 202). By running the clustering process for a variety of cluster sizes ($k = 2, 4, \dots, 50$) with 100 iterations, the scores can be compared. This process is conducted with a 5% sample of the overall scaled population data ($n = 683k$). While more clusters are usually producing more accurate results, the goal is finding a balance between a number as low and an accuracy as high as possible. For this, the elbow method can be applied in which the number of clusters is set at the point where the curve becomes less steep (AN.6.2, Figure 91). Here, 16 clusters are chosen. Next, all remaining variables are used to cluster the scaled population ($n = 13,658,311$). This is done with 100 iterations and including non-applicable variable entries (e.g., no indication where job is located as person goes to school). This results in the distribution of entries by cluster shown in Figure 35. The individuals are grouped in clusters of relatively homogenous characters, between 400k and 1.2M people per cluster.

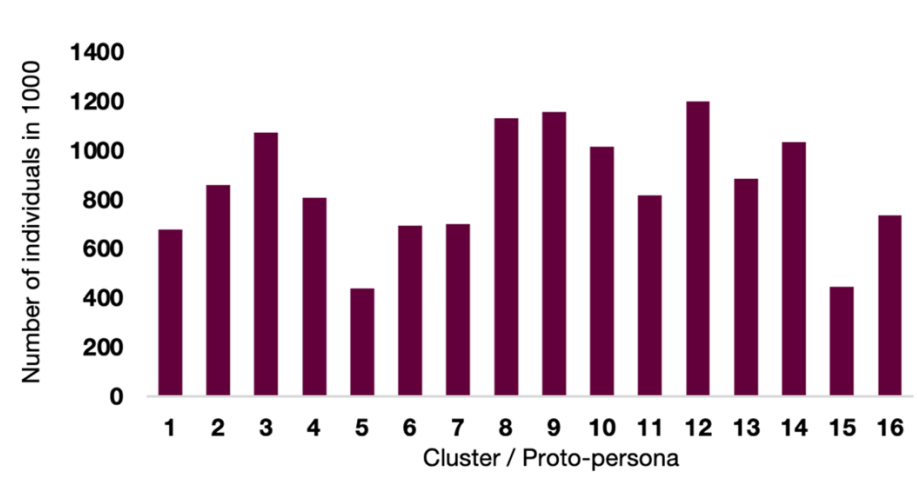


Figure 35: Distribution of entries by cluster for Paris (Gall et al., 2023d)

The clusters represent PPs. A selection of the central values of the cluster outcomes are shown in Table 8. The table shows the simplified meaning behind the majority of attributes that have been used for clustering, including information concerning the household (e.g., number of children and household members), individual socio-demographics (e.g., degree, activity location, origin), as well as supplementary information (e.g., parking spot availability or housing type).

To test the accuracy of the clusters, the most frequent clusters are chosen to compare its cluster central values and values of all entries assigned to the cluster. The numerical variables show a high accuracy across the variables. For the categorical data, some have very high accuracies and indicate that nearly 100% of data entries share the central value of the PP. In others, values under 50% appear. However, these are primarily in variables with many categories and all values are sufficiently high to evaluate the cluster results as solid and, with the limitation inherent to clustering over 13 million entries into 16 PPs, representative.

Table 8: Selected central values for 16 clusters / proto-personas (Gall et al., 2023d)

PP	Rooms	Child <5	Houshold	Car	Couple	Socio-prof.	Degree	Student	Parking	Activity loc.	Birthplace
1	4	1	4	1	yes	without job		yes	yes	in municip.	in dep.
2	4	1	4	1		higher ed.	Master			outs. dep.	abroad
3	4		2	1		retired	Vocational		yes		outs. region
4	2		1	1	yes	higher ed.	Master			outs. dep.	outs. region
5	4	1	4	1		employees	Vocational		yes	outs. municip.	abroad
6	3		3	1	yes	without job		yes		in municip.	in dep.
7	5		4	2		higher ed.	Master		yes	outs. dep.	outs. dep.
8	4	1	4	1	yes	without job					in dep.
9	3		3	1	yes	employees	Vocational			outs. dep.	outs. dep.
10	2		1		yes	higher ed.	Master			in municip.	abroad
11	4	1	4	1		without job	Vocational		yes		abroad
12	4		2	1		higher ed.	Master		yes	outs. dep.	outs. region
13	5		3	2	yes	intermediary	Technician		yes	outs. municip.	in dep.
14	5		4	2	yes	without job	College	yes	yes		outs. dep.
15	2		2		yes	without job	Highschool				abroad
16	3		1	1	yes	retired	Vocational				outs. region

PP	Way of life	Gender	Status	Housing	Size sqm	Activity	Empl. Time	Transport	Type
1	Child of couple	F	Single	Owner	60-80	< 14 years			Apartment
2	Couple with children	M	Married	Owner	80-100	Employed	Full time	Public transport	Apartment
3	Adults without children	M	Married	Owner	80-100	Retired			House
4	Adults	M	Single	Tenant	40-60	Employed	Full time	Public transport	Apartment
5	Couple with children	F	Married	Owner	60-80	Employed	Full time	Car	Apartment
6	Children of single parent	M	Single	Tenant social housing	60-80	< 14 years			Apartment
7	Couple with children	F	Married	Owner	120+	Employed	Full time	Car	House
8	Child of a couple	M	Single	Tenant social housing	80-100	< 14 years			Apartment
9	Single parent	F	Single	Tenant social housing	60-80	Employed	Full time	Public transport	Apartment
10	Single under 40	F	Single	Tenant	< 30	Employed	Full time	Public transport	Apartment
11	Couple with children	F	Married	Tenant social housing	60-80	Unemployed			Apartment
12	Adult without children	M	Married	Owner	60-80	Employed	Full time	Car	Apartment
13	Child of a couple	M	Single	Owner	80-100	Employed	Full time	Car	House
14	Child of a couple	M	Single	Owner	120+	Students			House
15	Single under 40	M	Single	Tenant	< 30	Unemployed			Apartment
16	Single over 40	F	Widow	Owner	40-60	Retired			Apartment

These 16 clusters represent groups of people with shared mix of attributes linked to the way of life and mobility behaviours. As an example, PP16 (n=736k) is a widowed woman living alone in a 3-room, 40-60 sqm apartment in Paris. She owns her apartment in a multi-unit building but does not own a car. She holds a vocational degree and is retired. Originally from another metropolitan region in France, she moved to Paris. This sample PP shows that with the performed process, comprehensible descriptive profiles can be generated.²²

Step 4: Proto-personas per age group and area

The clusters represent PPs which do not appear equally often across age groups and area. The objective was developing personas independently of age and area to focus on socio-economic characteristics and introduce these values via scenario variation. However, these variables can be re-associated and analysed. The distribution is organised by cluster, age group (0-14 years, 15-29 years, 30-44 years, 45-59 years, 60+ years) and geographical areas (Table 9). This provides an idea in how far all personas can describe sufficient varying classes and represent groups such as children. For example, for the age group of 0 to 14 years, ten clusters have occurrences, with PP8 being the strongest with occurrences between 3 and 5%.

²² The reader can perform the exercise for the remaining clusters on the basis of Table 8 (central PP values), Table 7 (variables), and Table 51 (codes for categorical variables).

While less personas appear in the under 15 and over 60 years group, sufficient PPs are included in both to represent a diversity across the age group.

For the distribution per area, we distinguish between inner Paris, the surrounding Métropole du Grand Paris without Paris (MGP), Paris-Saclay (CPS), and the remaining parts of the Île-de-France (IDF) region. The different percentages show the different distributions of personas across the areas. For example, PP10 is the most dominant across age groups in Paris.

Table 9: Cluster occurrences per area and age group in percentage (100% for each area, showing values from 0.5% upwards; Gall et al., 2023d)

PP	Paris	MGP	CPS	IDF	Paris	MGP	CPS	IDF	Paris	MGP	CPS	IDF	Paris	MGP	CPS	IDF	Paris	MGP	CPS	IDF	TOTAL	
1	1%	3%	2%	2%	1%	1%	1%	1%			1%	1%	1%	1%							676k	
2	2%	2%	1%	2%	2%	2%	1%	1%	2%	2%	1%	1%	2%	1%	1%	1%					859k	
3						1%	1%	1%			1%	1%	1%	1%	2%	2%	2%	3%	4%	6%	5%	1,072k
4					1%	1%	1%	1%	1%	2%	2%	2%	1%	1%	1%	1%	1%	2%	2%	1%	2%	806k
5			1%	2%	1%	1%	1%	1%			1%	1%	1%	1%	1%	1%						438k
6	2%	1%	1%	1%	2%	1%	1%	1%	3%	1%	1%	1%	2%	1%	1%	1%	2%	1%	1%	1%		693k
7		1%	1%	1%		1%	1%	1%		1%	1%	1%	1%	1%	2%	2%						700k
8	3%	5%	4%	4%	1%	1%	1%	1%	2%	3%	2%	3%	1%	1%		1%	1%	1%				1,131k
9	1%	1%	1%	1%	2%	2%	4%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%	2%		1,155k
10					6%	1%	2%	1%	5%	1%	1%	1%	3%	1%	1%	1%	3%	2%	2%	2%		1,013k
11	2%	2%	2%	2%	1%	1%	1%	1%	1%	2%	1%	1%	1%	1%	1%	1%	1%	1%	1%	1%		816k
12					1%	1%	2%	1%	1%	2%	2%	2%	1%	2%	2%	2%	4%	4%	5%	4%		1,199k
13		1%	2%	1%		2%	2%	2%		1%	2%	2%		2%	2%	2%			1%	1%	1%	885k
14	1%	2%	3%	2%	1%	3%	3%	3%	1%	1%	1%	1%	1%	2%	3%	2%	1%	1%				1,034k
15					3%			1%	2%	1%		1%	1%				2%					444k
16					2%			1%	3%	1%		1%	2%	1%	1%	1%	3%	2%	2%	2%		736k
	308k	183k	31k	1,972k	548k	169k	35k	1,947k	545k	187k	33k	2,157k	451k	174k	34k	2,012k	560k	180k	39k	2,094k	13,658k	

Step 5: PP validity test for mobility

A challenging element in persona development is validating their accuracy. Even when working with a PP without qualitative attributes, it must be validated that choices of attributes and clustering approach can lead to personas that represent variations in urban mobility. Two approaches can be used for this.

First, a subjective visual approach allows to validate the representativeness of the underlying data. If considered relevant, specific personas can be added, for example, underrepresented personas such as people with reduced mobility. Second, mobility surveys can be used to test if statistically significant differences in mobility behaviours across the PPs can be identified. In this paper, this is tested with the mobility of people survey (EMP, 2022) which details what mobility-related resources are available (e.g., driving license, car) and what trips are done where and when on a given day. All entries are considered where both origin and destination of trips were inside the Île-de-France region.

To match mobility data with the PP, shared variables are used.²³ The results show that differences between categories are in line with expectations. To exemplify this analysis, a random data entry that is matched to PP16 is chosen. A selection of the assigned information is: One person, female, single, retired, one car, two trips, first starting at 11:45:00, average duration 15 minutes, with a two-hour activity in between, and a 1 km distance. This fits the prior description of PP16. After repeating this process multiple times, it can be concluded that the PPs describe successfully varying mobility behaviours. However, the matching process on few shared variables, as well

²³ I.e., household size (+/-1), gender, activity type (TACT), and number of cars (+/-1).

as the exclusion of under 16-year-olds due to lack of data bear potential for future improvements.

Step 6: Uncertainty/trend compilation

The last steps described preparatory steps with today's data. To integrate possible futures via scenarios, uncertainties and trends can be used to redistribute PPs. This process is described in the next steps. Trends are developments that are assumed to materialise. For example, a continuing ageing of the society, a stable male/female distribution, or a population increase for an area. Uncertainties are contextually relevant attributes that are assumed to change but for which it is impossible to be certain of the direction of change. This might be the level of private car ownership or the willingness to take public transport. Each of them can vary. For example, the car ownership might range between 0.8 to 1 per person based on socio-economic and political developments (currently one on average). Some key trends (Table 10) and critical uncertainties (Table 11) were chosen for this study by the author in collaboration with the research team based on data availability and relevance for urban mobility.

Table 10: Compilation of trends (Gall et al., 2023d)

Trends	Description	Values		
		Area	Growth rate	
Annual population growth	The population is assumed to continue to grow. The central (incl. migration) scenario (INSEE, 2017) is considered for Paris and its environments (equalling petite-couronne and MGP). The IDF data (INSEE, 2011) is adapted by overall population to IDF without Paris and MGP.	Paris	0.4%	
		MGP	0.6%	
		IDF/CPS	0.13%	
Ageing	The demographic ageing process leads to an increase in the age group of 60+. Different values are calculated based on statistical assumptions from INSEE (2017).	Age group	Female	Male
		0-14	0.00	0.02
		15-29	-0.07	-0.08
		30-44	0.00	-0.14
		45-59	-0.03	-0.02
		60+	1.65	2.50

Table 11: Compilation of uncertainties (Gall et al., 2023d)

Uncertainties	Description	Range	Sources
U1: Car ownership	Car ownership, in particular in Paris, is assumed to decrease, while in more remote places an increase is possible. Changing technology, prices, and policymaking allows various assumptions.	Stable to less inside Paris/MGP, less to more outside MGP	INSEE, 2021
U2: Work/study location	With increasing transportation speed and trends like working-from-home, more people might work further away. Congestion or concepts like the 15-minute city or urban villages could counteract.	Across all regions significant possible changes.	L'Institut Paris Region, 2020

Uncertainties	Description	Range	Sources
U3: Household size	Household sizes are assumed to decrease. However, its level is unknown.	Decreasing, strongest inside Paris	OECD, 2011

Step 7: Future trend integration

These key trends are integrated depending on PP, age-group, and timescale. An anticipated annual population growth rate can be applied to each of the PPs via their respective occurrence rate (weight) that results from the clustering. On the other hand, an ageing society would lead to a proportional shifting of PPs by age-group. Based on the population and ageing forecasts from the statistical service of France (INSEE, 2017), growth rates (Table 12) are calculated which are equally applied to all PP within one area. The growth rate is calculated as combined value of both trends.

Table 12: Annual growth rates in percent for each category, based on INSEE 2011, INSEE 2017 (Attention: Values do not refer to Ile-de-France but IDF without Paris, MGP and CPS; Gall et al., 2023d)

Age groups	0-14 y.		15-29 y.		30-44 y.		45-59 y.		60+ y.	
	M	F	M	F	M	F	M	F	M	F
Paris	+0.02	+/-0	-0.08	-0.07	-0.14	0	-0.02	-0.03	+2.5	+1.7
MGP	+0.03	+0.01	-0.07	-0.06	-0.13	+0.01	-0.01	-0.02	+2.5	+1.7
CPS	+0.02	+/-0	-0.08	-0.07	-0.14	+0.01	-0.02	-0.03	+2.5	+1.7
IDF	+0.02	+/-0	-0.08	-0.07	-0.14	+/-0	-0.02	-0.03	+2.5	+1.7

Step 8: Uncertainties' values per scenario

The key difference to step 7 is that uncertainties are not applied equally but dependent on an underlying scenario. A number of different possible scenarios (usually 4-7) is defined for a particular year in the future, in this case 2030 (Table 13). Each scenario can be complemented with a name, narrative, and set of associated, application-dependent information. For the use case of this paper, three uncertainties and a numeric adaptation for each is defined. For their adaptation, scenario archetypes can be used (Dator, 2019; Fergnani and Jackson, 2019), in particular those of the mobility sector (Miskolczi et al., 2021). Building on these scenarios, values for each uncertainty are set to create coherent scenarios and a wider distribution across the variables (

Table 14).

Table 13: Four archetypical scenarios (Miskolczi et al., 2021)

Scenario	Description
S1: Grumpy old transport	No significant changes to the current status.
S2: At an easy pace	Slow, consistent change across fields.
S3: Mine is yours	Strong shift towards a shared economy and mobility system (incl. MaaS)
S4: Tech eager	Technology as driving force for majority of future mobility

Table 14: Trends and uncertainties quantified and adapted by authors for each scenario (Gall et al., 2023d)

Scenarios	U1: Car ownership	U2: Proximity of work/study locations	U3: Household sizes
S1	Increase (+5%)	Stable (+/-0%)	Stable (+/-0%)
S2	Decrease (-5%)	More local (+/- 1.5%/3%)	Decrease (-5%)
S3	Decrease (-5%)	More local (+/- 2%/4%)	Increase (+10%)
S4	Stable (+/-0%)	Less local (-/+ 1.5%/3%)	Strong decrease (-10%)

Step 9: Redistribute PP by scenario

Three options exist to adapt the PP for each future scenario. *The distribution of the PP can be adapted to best match the values provided for the uncertainties.* Second and if necessary, certain attributes of the present PP can be adapted to better allow the matching of future uncertainties. Third, some or all of PPs could be adapted differently for the scenarios. The latter would lead to a much higher number of personas, defeating its purpose.

The focus of this study is on the former option as it is deemed the optimal case for the methodology. Two steps need to be conducted. First, the growth and demographic change scales the overall distribution. The growth rates (Table 12) are applied to scale the PPs without changing the proportion. This constitutes the basis for all scenarios. Next, changes of certain impacts shall be reflected as accurate as possible by changing the distribution of personas. This is done by optimising the initial population weights so that uncertainty-based target values are reached in the future scenarios. The target scenarios are characterised by target mean values of numerical attributes across the overall population and anticipated target shares of persons with specific attribute values for nominal attributes. The following formula outlines the inputs and basis for the fitting process:

Persona variables and constants

- $K \in \mathbb{N}$: Number of personas
- $\omega'_k \in (0,1)$: Initial population share per persona k (baseline)
- $\omega_k \in (0,1)$: Population share per persona k (to be chosen)

Attribute constants

- \mathcal{A} : Set of attributes with a mean target value
- $a_k \in \mathbb{R}$: Value of attribute A in persona k
- $\hat{A} \in \mathbb{R}$: Target mean value for attribute A
- \mathcal{B} : Set of attributes with a target share per value
- \mathcal{V}_B : Set of values that are permissible for attribute B
- $b_{k,v} \in \{0,1\}$: Defines whether attribute B in persona k has value v
- $\hat{B}_v \in \{0,1\}$: Target share for value v of attribute B

The target share values need to fulfil:

$$\sum_{v \in \mathcal{V}_B} B_v \leq 1. \quad \forall B \in \mathcal{B}$$

If target shares for all possible values are given, equality must hold.

Optimisation constants

- ξ_{AB} : Objective weight for attribute AB
- α : Regularisation weight

Problem formulation

$$\begin{aligned}
 \min_{\omega_k} \quad & \sum_{A \in \mathcal{A}} \xi_A \left(\hat{A} - \sum_k \omega_k a_k \right)^2 \\
 + \quad & \sum_{B \in \mathcal{B}} \sum_{v \in V_B} \xi_B \left(\hat{B}_v - \sum_k \omega_k b_{k,v} \right)^2 \\
 & + \alpha \sum_k (\omega_k - \omega'_k)^2 \\
 \text{s. t.} \quad & \sum_k \omega_k > 0
 \end{aligned} \tag{1}$$

The first term in the objective calculates the mean of an attribute a given the updated weights and compares it to the required target value. Similarly, for nominal attribute values where a target value has been defined, the second term compares the obtained share of all PPs that have this specific value with the requested share. Each objective (representing an attribute or an attribute value) can be prioritised through a weighting factor. For attributes with higher attribute weights, matching their target value will be enforced with higher importance than for other attributes. Finally, a regularisation term is introduced which allows to give importance to not deviating too strongly from the initial weights of each persona. The regularisation weight defines whether the weights will be adapted in an aggressive way (increasing few personas strongly) or more uniform (increasing many personas carefully), but also has an impact on how well the posed target values can be attained.

In the present use case, the number of cars has a weight of 0.4, household size 0.3, work/study location 0.3 and a weight of 0.1 was given to the regularisation term to keep the variation between initial and final weights as small as possible. The outcomes are provided in the results section.

Step 10: Create personas and synthetic populations (SPs)

Finally, present and future sets of PPs and their distributions are used to create *full personas*. The difference to other processes is that the starting point (age, characteristics, location, activity chain) is not defined by the designer but instead comes from the underlying evidence-based approach and the supplementary information. Simultaneously, PPs distribution by area, in combination with travel surveys, and registries of residential, work, commercial, and leisure activities can be used to generate one present, and a set of *future SPs*. Building on the additional information assigned from the mobility survey to the personas (e.g., most common activity chains), qualitative persona creation methods allow building a set of personas

(incl., for example, name, photo, location (Vallet et al., 2020))²⁴. This is described by way of example in the results section. Further, building on Vallet et al. (2022), we can use the generated distributions and profiles for the generation of multiple synthetic populations. The only component that needs to be changed in the synthesis process are the initial weights in the census information. As, by using the clustering algorithm, a persona can be assigned to each record in the census data, their weights can be adapted according to the reweighting process. Applying this technique and analysing simulation outcomes based on these future SPs has been conducted separately in parallel research.

Outputs

The first output is a quantitative distribution of PPs across scenarios. This data set remains linked to the initial census data and can aid the process of scaling up and redistributing the census entries to result in new quantitative insights on varying possible futures, as well as feed quantitative design approaches. Figure 36 shows the distributions for two of the geographical areas, i.e., Paris and CPS, as examples for the varying distributions across areas and scenarios.²⁵ The distribution for the 2019 base and the four archetypical scenarios is provided. We can analyse two information from the figure. First, all four scenarios have a higher population, clearly visible for Paris and slightly for CPS. Second, each PP is represented by a colour and changes its occurrence from one scenario to another.

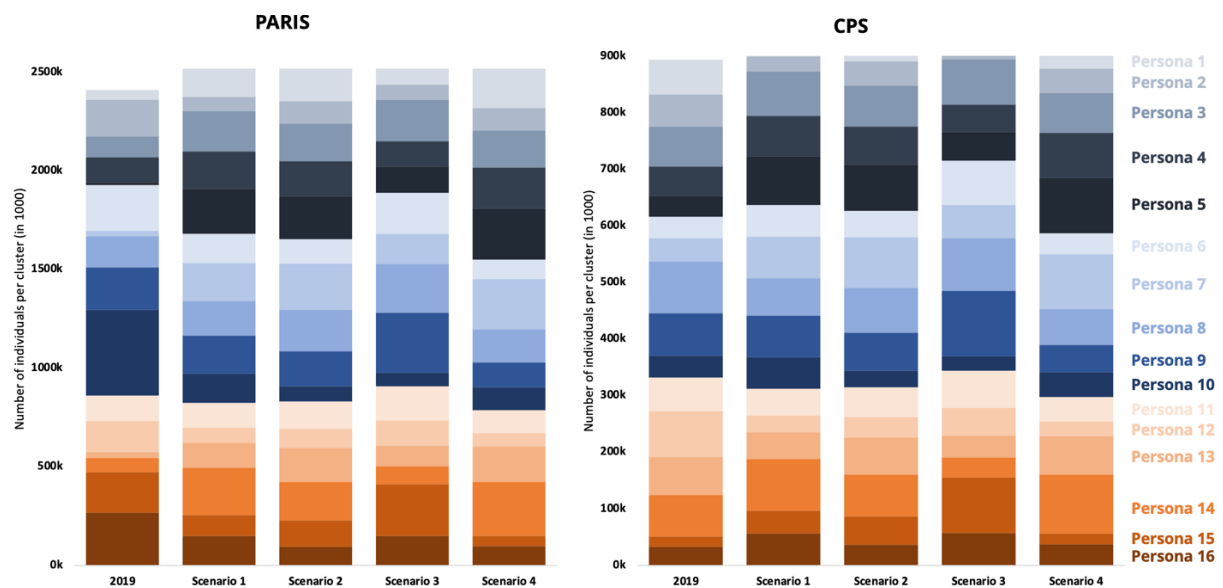


Figure 36: Resulting distribution of PP (in 1000s) for 2019 (census base year) and 2030 scenarios using outputs from reweighting and population growth rates per area (Gall et al., 2023d)

The information from the PPs, enriched with information from the mobility survey, can feed the creation process of data-driven qualitative personas. An example persona for the PP10 (Annex AN.6.2) has been created by adapting an existing persona template (xtensio, 2022). This work and example focus on the individual. In future works, existing data on household level could find integration in the process.

²⁴ A full set of personas based on this approach are available online: <https://urban-mobility-futures.notion.site/Personas-aa3b30f47c354220bc025dd7edb207cd?pvs=4>

²⁵ The fitting process resulted in deviation values of maximum 3% between targeted values and actual results (Annex AN.6.1 Table 56).

5.1.3.1 Agent-based simulations of scenarios

Making use of the created scenarios and the according synthetic population inputs of the previous section, this study presents a novel approach to simulate the urban mobility system of 2030 for IDF using MATSim. *The analysis considers four base scenarios incorporating each the new metro line 18 and tram 12 as part of the Grand Paris Express while using four different synthetic populations.* Additionally, a second set of four simulations is performed by introducing an on-demand mobility solution with shared automated electric vehicles (SAEVs).

Introduction and context

IDF and CPS (Figure 37), are facing significant urban mobility challenges due to rapid population growth, congestion, and environmental concerns. To address these, the region is investing in public transport infrastructure, such as the metro line 18, the southmost extension of the Grand Paris Express. In addition, emerging mobility solutions, such as SAEVs are considered by public and private actors to play an essential role in the future urban mobility ecosystem. A particular potential benefit is seen in the intermodal connection between areas that have traditionally and still today remain highly dependent on personal vehicles and stations of mass transit (RER/metro/tram).

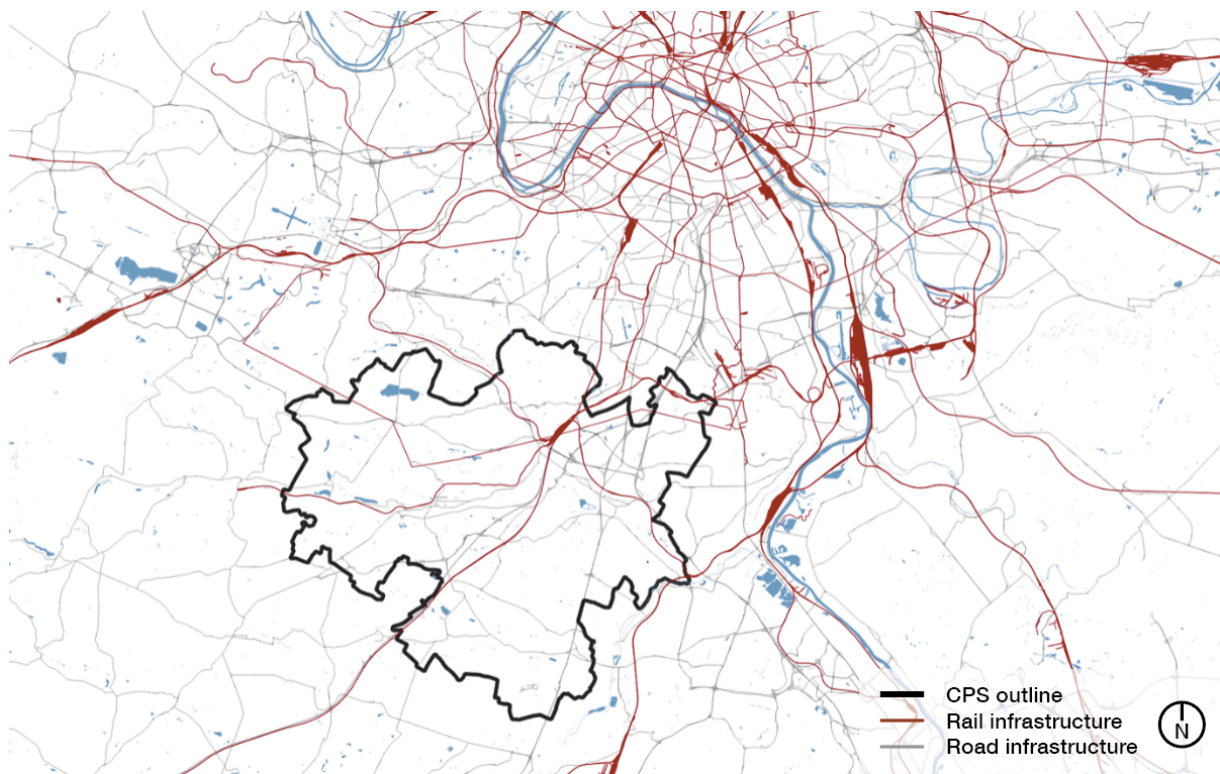


Figure 37: Map of Paris-Saclay (bold black outline) south of Paris, showing primary road infrastructure (grey), and rail-based transport infrastructure (red) in 2030 (Source: OpenStreetMap, 2022; Chouaki, 2023)

To quantify the potential impacts – including its direct impacts such as reduced costs or increased accessibility or indirect ones such as GHG emissions – and thus assess the effectiveness of these interventions, this study employs MATSim. For the method described here, we use a *two-step approach to simulate the urban mobility system of 2030*. First, we simulate four base scenarios considering the new metro line 18 and tram 12 as well as trends and uncertainties by generating four different synthetic populations (Figure 38). These populations represent various demographic,

socioeconomic, and spatial distribution patterns based on existing data sources and projections for the year 2030.

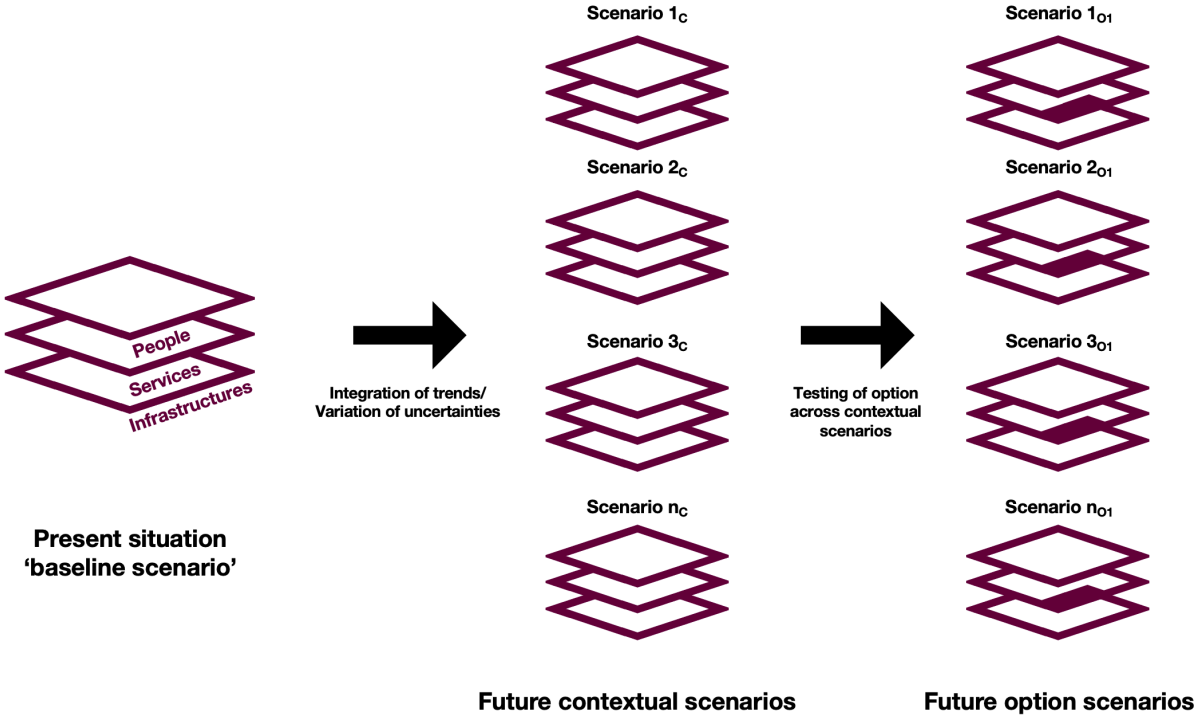


Figure 38: Scenario simulation logic. Left: Simulation of present urban mobility system made of three layers (people/services/infrastructures). Centre: Four contextual future scenarios. Right: Contextual scenarios with added mobility service (CC BY 4.0)

In the second step, we introduce an on-demand mobility solution using SAEVs and run an additional set of four simulations. This approach allows us to evaluate *the potential impacts of SAEVs on travel behaviour, mode choice, congestion, and greenhouse gas emissions*, as well as their synergies with public transport infrastructure. Some technical details are listed below:

- For performance reasons, the simulation is run with 1% of the overall population, deemed sufficient for accurate comparisons but not necessarily to deduct the most accurate stand-alone values.
- Each simulation is run 100 times on the scale of the Île-de-France region. In the case of the SAEV, each has a passenger capacity of four people, and 200 shuttles are introduced in the Paris-Saclay area (equalling non-linearly scalable more for a 100% synthetic population). At the start of each simulation circle, the SAEVs are located at one of 100 demand peak locations resulting from the base contextual scenarios.
- For the simulation, the cost assumed in the choice model is €0.30 per km per passenger, independent how many people are sharing the vehicle.²⁶ In between trips, shuttles are automatically rebalanced according to probability of future trip locations. The SAEVs can only be used to go from or to rail-based public

²⁶ A more complex cost model is used for the assessment part. While two different approaches can make sense for various reasons, an alignment of model scoring, and assessment is recommended for future works.

transportation (i.e., RER, metro, and tram), not to go directly from trip origin to destination.

Scenario simulation method applied to sustainability impact assessment

The objective is to test the utility of future scenario simulations to respond to predefined problem statements relevant for a sustainable urban mobility transition when a potential new mobility solution is evaluated. Where possible, future assumptions are made on existing data and projections (i.e., population development, public transport growth, decreasing emissions per passenger kilometre). For uncertain developments, such as changing behaviours or access to mobility resources, variations are integrated via a set of future scenarios.

The tested solution is the introduction of SAEVs of about 20k vehicles²⁷ with a capacity of four passengers each. We postulate that the approach and its outcomes are promising to gain *more fine-grained insights across areas, modes, and user groups, as well as to permit a more structured consideration of future uncertainties and their significant impact on the success or failure of responding with new solutions* to sustainable urban mobility objectives. We first present the use case question before discussing the indicators chosen to respond to the question and the methodological considerations. Finally, we present and discuss the results.

Building on assessment frameworks and indicator sets introduced in the section on sustainable urban mobility, we choose one of the most common indicators for each dimension of sustainability. Environmental sustainability as GHG emissions measured in CO₂e, social sustainability as accessibility to opportunity, and economic sustainability as the mobility-related expenses. The latter are often extended by costs of the maintenance and construction of infrastructure. However, our focus lies on the individual choices' impacts, thus we exclude them from the calculations but suggest that they should be considered in the design and decision-making process. The resulting use case question is:

Does the introduction of SAEVs reduce CO₂e, travel time, and mobility-related expenses, and if yes, by how much?

The three indicators (Figure 39) are assessed at the Paris-Saclay scale for the present and each of the 2030 scenarios with and without SAEV. For clarity purposes of the results, many of the calculations take the average values of the scenarios with equal weight. Finally, we look at the values of each indicator and the variance per persona to see how, for example, who is most contributing to emissions today or benefits most from time savings of the introduction of SAEV. The following sections describe the methodology and underlying assumption for each indicator.

²⁷ The simulations are run at 1% of the synthetic population for performance reasons, using 200 vehicles. While the results can be scaled up for other modes, no perfect linear scaling is possible for shared MoD vehicles due to increased sharing of vehicles in case of more people's behaviour simulated. The 200 vehicles are converted to an assumed equivalent of about 20,000 vehicles with limitations on scaling synthetic populations detailed by Kagho et al. (2022).

**Planet/
Environmental**



Emissions

CO2 equivalent (CO2e)

**People/
Social**



Destination Accessibility

Time to reach destinations

**Profit/
Economic**



Mobility Cost

Cost of all trips

Figure 39: Three dimensions of simulated scenario impact assessment (CC BY 4.0)

CO2 equivalent emissions: The first indicator considers emissions, commonly referred to as GHG emissions or CO2 equivalent (CO2e) emissions. In both cases, different emissions, primarily carbon dioxide (CO2), methane (CH4), nitrous oxide (N2O) are transformed to an assumed equivalent of CO2 to permit easier impact comparisons.²⁸ The largest contributors are usually housing, mobility, and nutrition. As these simulations are for 24h, we provide daily averages or sums, expressed as CO2e from personal mobility between 0:00 and 23:59 at an average weekday. The values are based on the MATSim simulations run with 1% synthetic populations (SP) for IDF and multiplied by 100. The 2030 scenarios are calculated individually as well as an average of the four scenarios with equal weight (expressing equal probability). The emissions are calculated on mode-dependent CO2e-averages in kilograms per passenger kilometre (pkm). For example, a bus with average emissions of 1 kg CO2e per kilometre and an average occupancy of 50 people has a value of 0.02 kg CO2e/pkm. The values are resulting from current fleet constellations and their projections until 2030.

In the simulations, we distinguish between the modes Car, Passenger (person sharing a ride with somebody from the same household), Walk, Bike, Public Transport. The underlying CO2e/pkm values are set at 0.130 kg for cars, half for passengers, 0.025 kg for public transport, and 0 kg for active modes. For the 2030 scenarios, we assume a decrease of the average CO2e per vehicle (due to increased electric vehicle share and less older cars in the national fleet) to 0.080 kg, again half for passengers, 0.015 for public transport, mostly due to increasing gas and battery-electric buses and the metro extension and automatisisation. For the SAEV, we assume an average value of 0.030 kg CO2e per pkm. The following shows the indicator formulae.

Indicator 1: Total CO2e per scenario

Sum of kilometres per mode times CO2 equivalent per km per mode

$$\sum_{M=1}^4 KM_M CO_2e_M$$

(2)

²⁸ For reference, about 1.5-2.5 tons per person and year are often quoted if we want to remain under an increased temperature of +1.5-degree Celsius compared to preindustrial values. Today's per capita emissions range between 4.5 tons for bottom-up models and 12 or more for top-down models.

Indicator 2: Average CO2e per capita per scenario

Sum of kilometres per mode times CO2 equivalent per km per mode divided by population

$$\frac{\sum_{M=1}^4 KM_M CO_2e_M}{N} \quad (3)$$

Indicator 3: Sum CO2e per persona per scenario

For each persona: Sum of kilometres per mode times CO2 equivalent per km per mode

$$\sum_{M=1}^4 \sum_{P=1}^{16} KM_{M,P} CO_2e_{M,P} \quad (4)$$

Indicator 4: Average CO2e per persona per scenario

For each persona: Sum of kilometres per mode times CO2 equivalent per km per mode divided by number of people of P.

$$\frac{\sum_{M=1}^4 \sum_{P=1}^{16} KM_{M,P} CO_2e_{M,P}}{N_P} \quad (5)$$

Where:

- N : Total synthetic population taking trips within Paris-Saclay
- M : Mode (Car, Passenger, Public Transport, SAEV)
- P : Persona (n=16)
- KM_M : km per mode
- KM_{PP} : km per persona
- $KM_{M,PP}$: km per mode and persona
- CO_2e_m : CO²-equivalent per km per mode
- CO_2e_p : CO²-equivalent per persona

Accessibility: The second indicator is a direct impact for the people moving around which also affect the scoring as part of the MATSim simulations. Referring back to the UMS, an urban area functions as a spatial container for individuals to collaborate more and use resources more efficiently and effectively due to physical proximity. In the past (before 1860s), this physical proximity was defined by the duration which could be walked per day without negatively impacting the time needed to work, sleep, eat, etc. The duration per day is usually defined somewhere around 60, maximum 90 minutes per day, depending on the scale of city and with large global homogeneity despite minor cultural differences.²⁹ We thus aim to measure accessibility as an indicator aggregated over the population for reaching jobs and other opportunities in the urban context. Geurs and van Wee define accessibility as the ‘extent to which land-use and transport systems enable (groups of) individuals to reach activities or destinations by means of a (combination of) transport mode(s)’ (Geurs and van Wee, 2013, p. 128).

²⁹ See Marchetti, 1994, for initial analysis of globally homogenous commuting times, Bertraud, 2018, for urban growth dynamics and commuting durations, and Dong et al., 2022, for recent, data-driven analysis of daily commuting patterns.

As our focus on the impact of SAEVs, the question is to measure the change of accessibility across scenarios and with or without the service. Most commonly, accessibility is measured as potential reach in area or number of jobs/places that could potentially be reached. As outcomes of the simulations, we obtain actual numbers. Thus, we need to adapt and calculate a proxy value which we set at how long it takes to get somewhere and not how far the actual distance between the locations is, taking into consideration that locations do not change due to SAEVs, only across scenarios as result of different synthetic populations. A limitation of this approach is, among others, pointed out by Bertraud (2018, Ch. 5), who states that ‘an urban transport system that would solely minimize [sic] travel time between home and current jobs for all workers would result in poor mobility, as in the future, workers might not be able to reach many alternative jobs that would improve their job satisfaction or salary.’ We argue that the aggregated or averages values of individuals whose trip origins and destinations are distributed across the geographical area with representative densities act as sufficiently close proxy accessibility scale. The distances and durations, disaggregated by mode, are calculated per day. All values and settings are identical to those described for CO2e emissions. The formulae for can be found in Annex AN.6.4.

Cost: Finally, the actual individual costs are looked at. The values are given in euros and include direct costs (i.e., metro tickets, fuel costs, monetised car wear and tear) but do not consider generalised expenses such as road construction and maintenance or public transport expansion. We assume walking, biking, and using public transport for those having a subscription (Navigo Mensuel/Annuel) as free. Car trips are calculated at 90 cents per kilometre, passenger trips at half the value. Public transport is set at €2 per trip, capped at a daily maximum of €4 as otherwise a monthly subscription would be cheaper. SAEVs prices are building on the system of current taxi pricing scheme in the Paris region³⁰. We do not consider a minimum trip cost to enable short distance trips between homes and public transport hub. As SAEVs are supposed to be cheaper to traditional taxis due to sharing between customers, more efficient engines/driving styles resulting from automatised mobility, and potential public subsidy due to suburban setting, we assume a quarter of the current taxi prices, thus 0.65 cents as a pickup fee and 0.38 cents per kilometre. The formulae can be found in Annex AN.6.4.

Results of Paris scenario simulations

In this section, we show some of the key results from the scenario simulations. Figure 40 shows that the simulation results suggest that 20.86 kilotons CO2 equivalent (CO2e) are emitted per day resulting from people’s mobility. From this, 0.7 kilotons are emitted from trips starting and/or ending inside the Inter-council Partnership Paris-Saclay (CPS, yellow). With an assumption of constant CO2e per passenger kilometre values, the emissions increase significantly until 2030. The right-most bar shows that SAEVs can reduce the emissions by 50 tons in CPS and also have an impact on the rest of the Île-de-France region (blue).

³⁰ €1.53 per km for zone b in Paris region according to G7 data on 18 May 2023 ([#](https://www.g7.fr/en/paris-taxi-fares) and Pick-up fee of €2.6).

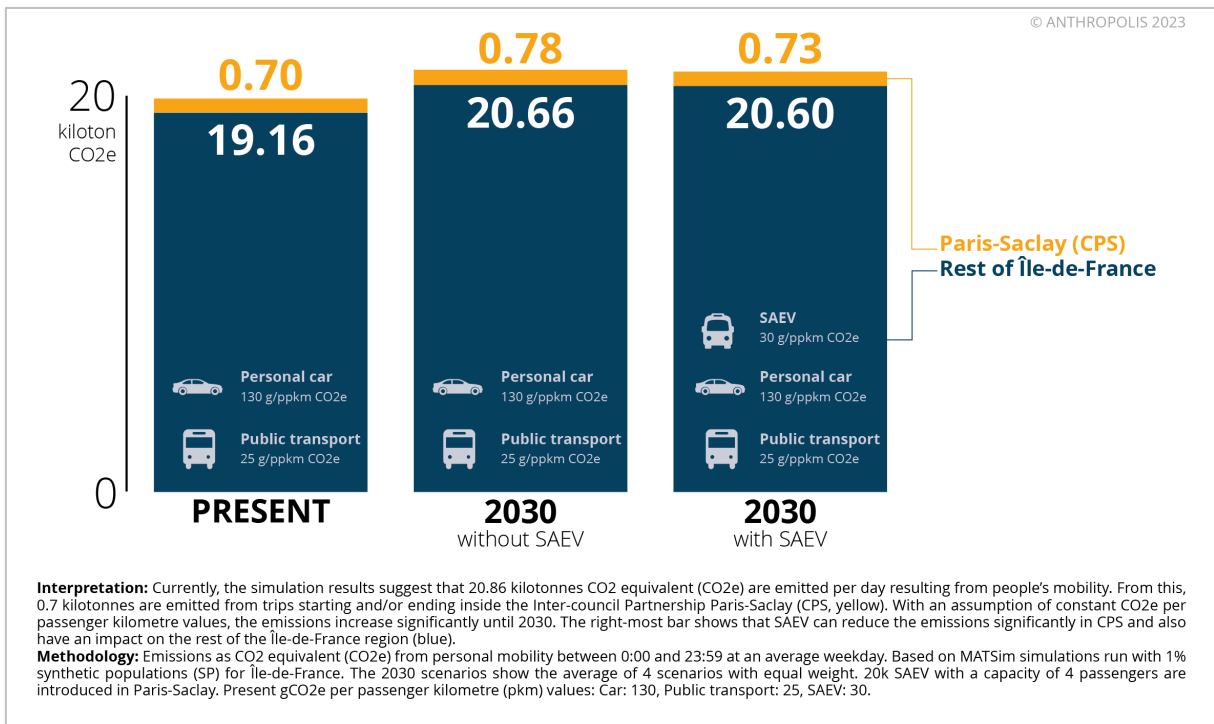


Figure 40: Estimated daily mobility emissions in Île-de-France. Impact of Shared Automatised Electric Vehicles (SAEV), without CO2e/pkm reduction by 2030 (CC BY 4.0)

If we assume a likely improve of vehicle engine efficiency and thus decrease of CO2e/pkm values by 2030, the results change significantly (Figure 41). The simulation results suggest that 20.86 kilotons CO2 equivalent (CO2e) are emitted per day resulting from people's mobility. From this, 0.7 kilotons are emitted from trips starting and/or ending inside the Inter-council Partnership Paris-Saclay (CPS, yellow). The right-most bar shows that SAEVs can reduce the emissions within CPS and also have an impact on the rest of the Île-de-France region (blue), e.g., due to decreased congestion.

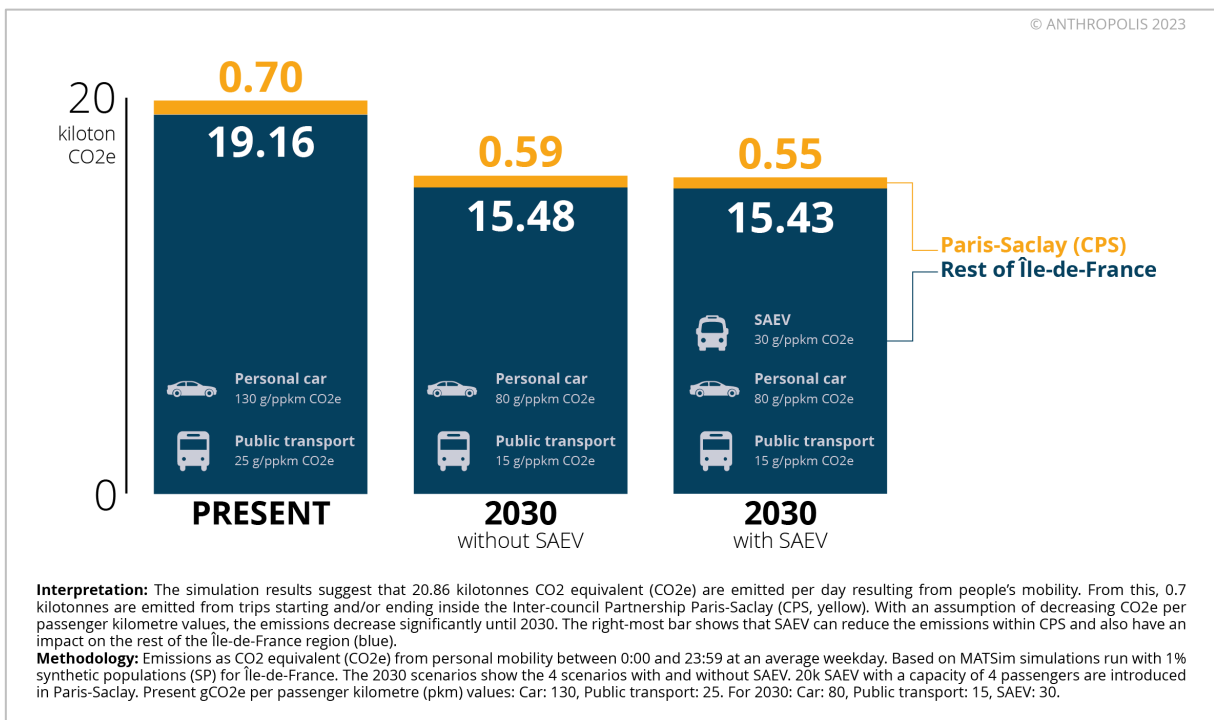


Figure 41: Estimated daily mobility emissions in Île-de-France. Impact of Shared Automatised Electric Vehicles (SAEV), assuming CO2e/pkm reduction by 2030 (CC BY 4.0)

For the following part, we zoom in on the trips starting and/or ending in Paris-Saclay. The same analysis, with the contribution of each mode (Figure 42), indicate that currently 697 tonnes CO2 equivalent (CO2e) are emitted per day resulting from personal mobility trips starting and/or ending inside the Inter-council Partnership Paris-Saclay. The largest contributor is the individual car, followed by car passengers and Public Transport. In the 2030 scenarios with SAEVs (rightmost bar), a small addition of emissions from SAEVs leads to a significant decrease of CO2e emissions from individual cars.

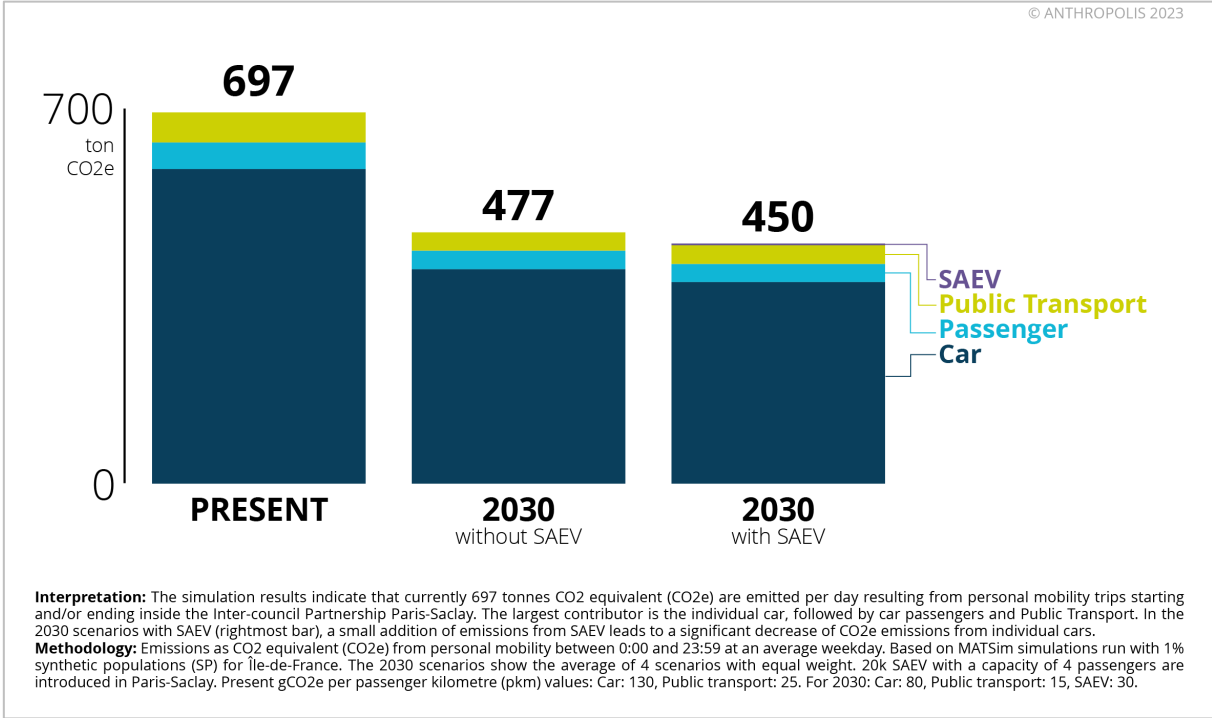


Figure 42: Estimated daily mobility emissions in Paris-Saclay. Impact of Shared Automatised Electric Vehicles (SAEV), assuming CO2e/pkm reduction by 2030 (CC BY 4.0)

Figure 43 shows the same information disaggregated by scenario. In the 2030 scenarios with SAEV, a small addition of emissions from SAEVs (purple) leads to a significant decrease of CO2e emissions from individual cars. The total decrease of emissions due to SAEVs range from -3.8% in the ‘At-an-easy-pace’ scenario’ up to -8% for the ‘Mine-is-yours’ and ‘Tech-eager’ scenarios.

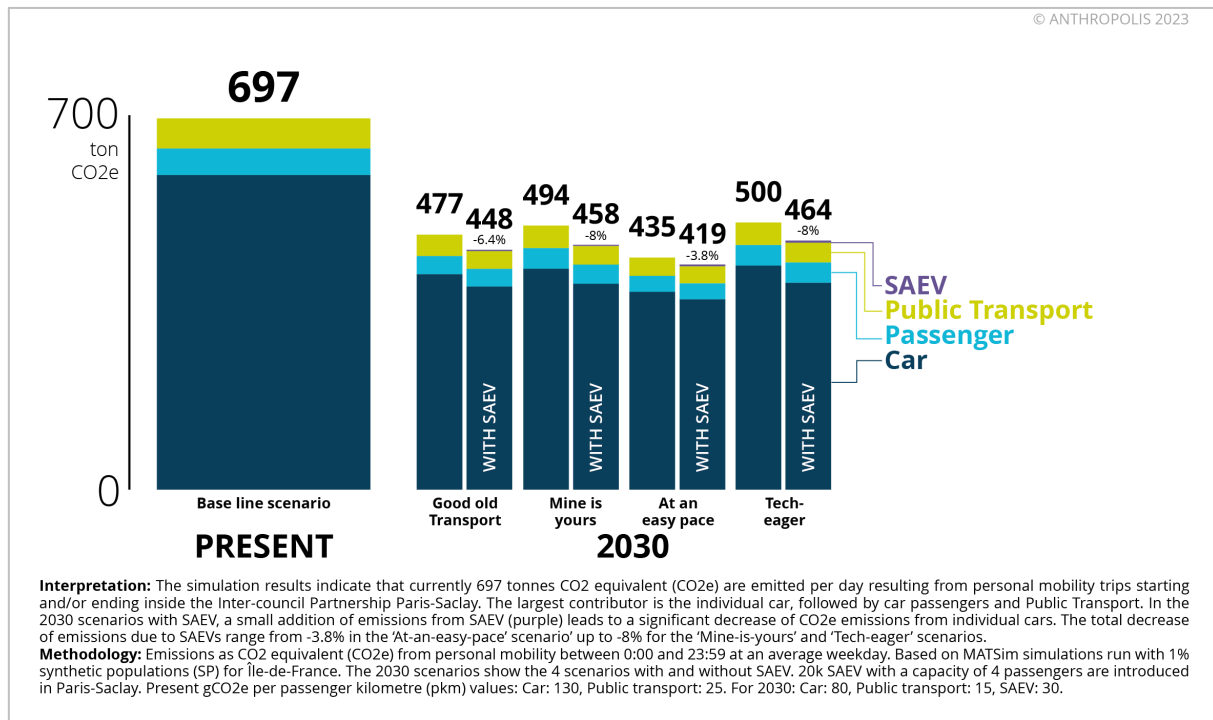


Figure 43: Estimated daily mobility emissions in Paris-Saclay. Impact of Shared Automatised Electric Vehicles (SAEV), assuming CO₂e/pkm reduction by 2030 (CC BY 4.0)

Aside from the data aggregated by scenario groups or scenarios, we can look at the impact of the individual personas (Figure 44 for first four personas, the other 12 are in Annex AN.6.4). For each of the 16 personas, a fictional name and data-based information on age and occupation are given. More complete information is available for each of the personas, in line with the method described in Chapter 5.3. The occurrence of each persona today and averaged across the 2030 scenarios is provided below, *restricted to those taking trips within CPS* (not fully representative of overall population but correlated). On the right, the average values for all 2030 scenarios are provided for CO₂e emissions, average daily distance, time spent commuting, and expenses. The bars show the respective variations for each persona. The graph shows that certain personas are significantly higher or lower than the average. The impact of SAEVs changes significantly across personas, affecting primarily those personas that are emitting more than average, thus those that are more car dependent.

As an example, we describe the meaning of the diagram for Persona 1 (P1). P1 is Céline Dupont and is 28 years old. Currently, about 121,000 individuals of that type are moving in the area of Paris-Saclay on a normal day. By 2030, an across-scenario average of about 141,000, thus an increase of about 17% is assumed. Compared to the daily 2030 average of 0.9 kg CO₂e emissions per day, Céline emits about 0.4 kg less. In 2030, regardless of with SAEVs or not, her daily CO₂e emissions decrease by 0.2 kg to 0.3 kg. A difference between the 2030 scenario sets can be observed in the other three values. For example, today, Céline spends about 19 minutes less than the 2030 average of 65 minutes per day for mobility. For the 2030 scenario without SAEV, this increases by 1 to 18 minutes less, or 47 minutes. In the 2030 scenarios with SAEV, the daily time savings increase to minus 22 minutes, or 43 minutes. This stems most likely from a potential combination of using SAEVs and/or indirect benefits from less traffic due to SAEVs and thus less cars. Similar observations can be made for the distance and costs. This concludes the assessment of SAEVs across scenarios via agent-based simulations. Further graphs and analysis are in Annex AN.6.4.

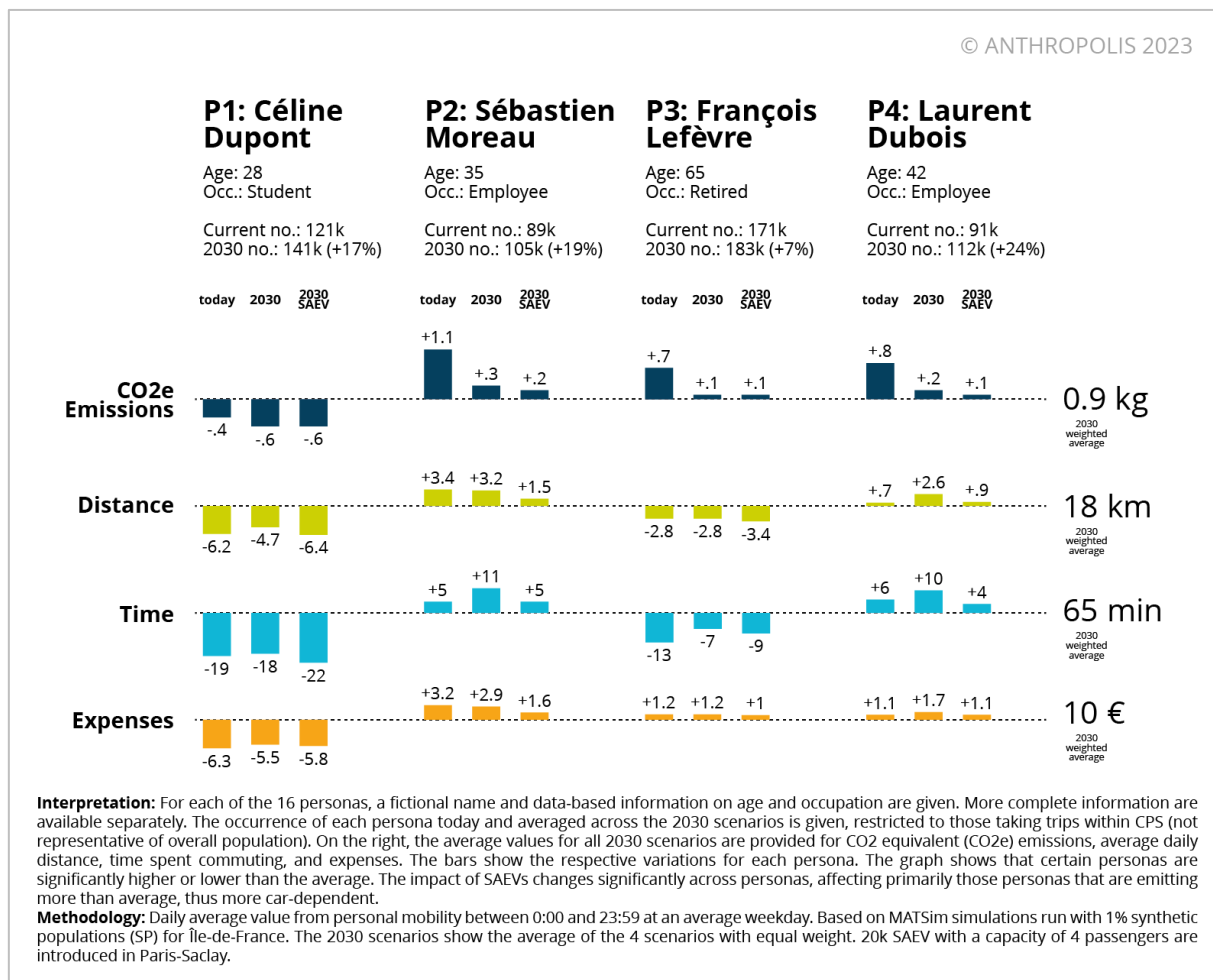


Figure 44: Daily values per persona for P1-P4. Impact of Shared Automatised Electric Vehicles (SAEV), assuming CO2e/pkm reduction by 2030 (CC BY 4.0)

5.1.3.2 Decision and design support tool for collaborative impact assessments

In some cases, the above method might not be feasible due to its required resources and a quicker solution is needed. For this, an alternative method has been created and tested in the context of transitioning towards more active mobility in the peri-urban context of the Saclay Plateau. The initial version was ideated during a one-week workshop in May 2022 with eight mobility and scenario experts focusing on sustainable and active mobility on the Saclay plateau.³¹ The two approaches are here presented as separate, parallel and complementary processes. They could be, however, imagined as subsequent methods.

For example, the below process helps to perform a rapid assessment of a proposed solution as well as expert-validation of scenarios and personas. In case of a positive initial feasibility assessment, the outputs can feed the agent-based simulation process described above. In the other direction, average impact values resulting from various standardised simulations could feed the simplified decision support tool. The following section describes the five steps of the process through a methodological lens. The process was digitised in an open access online tool which has been tested with individuals and in group settings. The outcomes of the latter are discussed after the method description.

³¹ The workshop details and supplementary information can be found in Annex AN.3.7

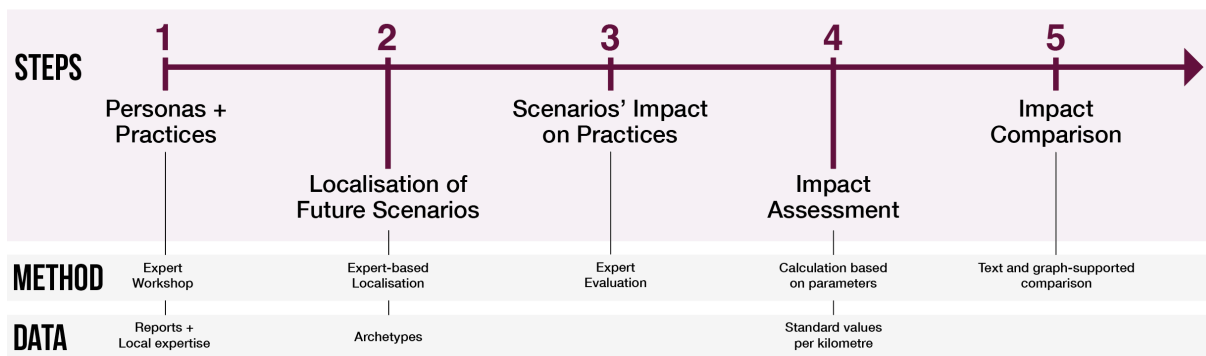






Figure 45: Process steps for decision-support tool (CC BY 4.0)

Step 1: Personas and their practices

First, personas are defined as intermediary design objects to permit a people-centred approach. For this, four personas are co-created through an expert-based process (Table 15). They do not aim to be comprehensive but instead to represent four key groups and allow to test the methodological framework. The photos were generated with Midjourney based on the persona descriptions (see Annex AN.6.5). The following makes use of the personas that were developed as part of the collaborative project. They could be extended or replaced by the previously introduced data-driven personas.

Table 15: Overview of personas used for decision-support tool (CC BY 4.0)

Name	Jacqueline	Thierry	Adrian	Rui
				
Profile	She works full-time at IRT SystemX as high manager, she does sports and stays healthy	Visitor, professor working, close to be retired	Part-time worker, Supermarket administrative office	International undergrad exchange student from China, studying at CentraleSupélec
Age	40	67	35	21
Preferences	She appreciates her privacy and has flexible work schedules She doesn't want to bike too much because she carries lots of bags around, she prefers to cycle, She has no children and no partner -> workaholic	Coming to the plateau for a week of guest lectures, he stays at Cité Universitaire Not in charge of children Using PT, but struggling because recently had a leg surgery	In charge of children (2 kindergarten, 1 primary school) Medium income level Time constrains (lots of activities and carry out many scheduled meetings)	Low budget She lives in the campus in one of the student's residencies She mainly gets to her daily activities by active mobility because she is sustainability-engaged, lack of



Name	Jacqueline	Thierry	Adrian	Rui
	Concerned but not strongly engaged with sustainability issues	Concerned by sustainability	Car user due to the complex daily mobility chain, and to respect time delays Sustainability is not the priority in his choices due to several constraints	alternatives, it is cheaper Sustainability is a priority


Step 2: Localisation of future scenarios

In the second step, four future scenarios are created to integrate future uncertainties and transitions (Table 16). This set of scenarios is a result from a collaborative scenario creation process and Transit-Oriented Development concepts (ITDP, 2020). The set of simplified scenarios is based on the same archetypical mobility scenarios introduced earlier: ‘grumpy old transport’, ‘mine is yours’, ‘at an easy pace’, and ‘tech-eager mobility’ (Miskolczi et al., 2021).

Further, and adapting the 2-by-2 scenario approach, the workshop participants decided on four critical, predominantly spatial uncertainties: *Population density, diversity of uses, intermodality, and access to public transport*. The result are four scenarios, named Saclay 2.0, Paris 2.0, Rural Campus, and Village Campus. Each of them is briefly described and assigned a numeric value (between one and four for intermodality (IM), mixed use (MU), density (DE), and public transport (PT)).

Table 16: Description of future scenarios for Paris-Saclay (CC BY 4.0)

Title	Description	IM	MU	DE	PT
 <p>Saclay 2.0</p>	<p>Continuation of today’s development. The Saclay Plateau today is dominated by universities and technology-related institutions. Some residential buildings and other functions exist and are growing. Nevertheless, on weekend or holiday periods, the plateau remains mostly empty. Saclay 2.0 would be the continuation of the current growth. More university and technology functions would grow, complemented by more residential buildings. Nevertheless, by 2030, the character of the plateau remains to be largely linked to university’s seasonality and depending on the incoming commuters, primarily between Tuesday and Thursday and barely staying or utilising other functions on the plateau.</p>	3	1	4	3
 <p>Paris 2.0</p>	<p>High-density, mixed-use neighbourhood. The second scenario is more optimistic on the integrated development of the plateau. It assumes that a large number of residential developments, going further than only student and international researcher housing, adds a critical mass of population density to allow for a variety of other functions to arise and remain active even in holiday seasons or weekends.</p>	4	4	4	4

	Title	Description	IM	MU	DE	PT
	Rural Campus	Low-density, low diversity rural district. This scenario describes mostly the plateau as it has been since the 1970s. While more offices and universities are added, its functions and character remain primarily rural. Residential functions, as well as the accompanying other functions, remain limited and their growth stagnates, maintaining primarily the status quo of activity and functional mix.	2	1	1	2
	Village Campus	High-density active core, surrounded by low-density. As a mix between the scenario 'Paris 2.0' and 'Rural Campus', this scenario is defined by overall low density and restricted developments. However, it has modern yet traditional French village cores with high level of mixed-use, walkability, and a range of bars and restaurants for students and other inhabitants of the plateau.	2	4	2	3

Step 3: Scenarios' impact on practices

Possible modes and combinations thereof are defined for each of the personas. For example, the options that require more walking are not suitable for Thierry as he had a recent leg surgery, while walking alone is not adequate for the personas living very far away. The input was how likely it is for each persona to use certain modes across scenarios, expressed in 0 = Unlikely, to 4 = Very likely. This was transformed into a percentage, calculated by dividing the respective likelihood score by the sum of all likelihoods for one persona and scenario.

In Table 17, we see the resulting probable *distance per mode* expressed as the equivalent of kilometres. This is transformed in average emission, energy demand, and burned calories, based on the values defined in Table 18. We use average values of CO₂e, energy (MJ), and calories burned per kilometre and translate them into *impacts per persona per scenario*. This shows, e.g., that Jacqueline has the highest impact in the 'rural campus' scenario, while Rui has the lowest impact in the same scenario.

Table 17: Calculated kilometres and impacts per mode/scenario/persona (KM = kilometres, PT = Public transport, MOD = Mobility on demand, MM = Micromobility, MJ = Megajoule, Cal = Calories)

	Scenarios		PT	MOD	Car	Bike	Walk	MM	kg CO₂e	MJ	Cal
Thierry	Saclay 2.0	KM	13.3	20.0	2.7	0.0	4.0	0.0	1.6	23	336
	Paris 2.0	KM	17.1	16.0	2.1	0.0	3.7	1.1	1.4	21	314
	Rural campus	KM	10.7	13.3	11.6	0.0	4.4	0.0	2.6	34	373
	Village campus	KM	12.3	14.2	8.0	0.0	4.3	1.2	2.1	29	362
Rui	Saclay 2.0	KM	1.3	0.5	0.0	0.9	1.0	0.6	0.1	1	73
	Paris 2.0	KM	1.2	0.6	0.0	0.8	0.9	0.7	0.1	1	67
	Rural campus	KM	1.4	0.0	0.0	1.6	1.3	0.1	0.0	0	101

	Scenarios		PT	MOD	Car	Bike	Walk	MM	kg CO2e	MJ	Cal
	Village campus	KM	1.0	0.7	0.4	0.8	0.9	0.4	0.1	2	63
Adrian	Saclay 2.0	KM	1.0	3.6	2.7	0.4	1.0	1.2	0.6	9	88
	Paris 2.0	KM	1.0	4.0	2.5	0.4	1.0	1.2	0.6	8	81
	Rural campus	KM	0.5	4.0	4.5	0.0	0.8	0.3	0.9	12	54
	Village campus	KM	0.4	4.3	3.8	0.0	0.7	0.7	0.8	11	53
Jacqueline	Saclay 2.0	KM	22.6	12.0	19.1	2.8	4.9	0.7	3.8	49	346
	Paris 2.0	KM	36.0	6.0	10.5	6.0	4.5	1.5	2.4	32	393
	Rural campus	KM	3.4	19.7	30.9	0.0	6.0	0.0	5.7	72	342
	Village campus	KM	25.3	7.6	19.6	2.5	5.1	1.9	3.7	47	346

Table 18: Underlying values for assessment (KM = kilometres, PT = Public transport, MOD = Mobility on demand, MM = Micromobility, MJ = Megajoule, Cal = Calories)³²

	PT	Car	MoD	MM	Bike	Walk
g CO2e	15	150	50	10	0	0
MJ	0.2	0.8	1.8	0	0	0.5
Calories	Calories burned cycling (20kmh) = 0.4 (MJ/kg/km) * weight (kg) * distance (km)					
	Calories burned walking = 1 (MJ/kg/km) * weight (kg) * distance (km)					

Step 4: Impact assessment across personas and scenarios

Next, we set an assumed population of 50,000 for the study area of the Saclay plateau, and a probability for each scenario (scenario Saclay 2.0: 40%, Paris 2.0: 15%, Rural campus: 25%, Village campus: 20%).³³ Further, we attribute each persona a weight, meaning the overall occurrence of each persona type in the overall population. Persona type Thierry gets a weight of 10%, Rui 60%, Adrian 20%, and Jacqueline 10%. This allows to get an *overall score*, as well as *disaggregated scores across scenarios and persona groups* (Table 19-Table 21). Up to this point, these numbers allow to identify priority areas. For example, we could focus on the highest emitter across the most likely scenarios or try to ensure a minimum level of accessibility for all.

32 CO2e: <https://datagir.ademe.fr/apps/mon-impact-transport/>, energy: <https://www.iea.org/data-and-statistics/charts/energy-intensity-of-passenger-transport-modes-2018>, calories: <https://caloriesburnedhq.com/calories-burned-biking/> (accessed 25 March 2023)

33 There are different schools of thought regarding the assignment of probabilities to scenarios. In this case, it was chosen to assign them as it permitted a more precise estimation of averaged future values which have been expressed as critical information for local decision-makers.

Table 19: Impact per persona and scenario per day

CO2e in tons				GIGAJOULE (GJ)				Cal/1000			
S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
8.0	6.9	12.8	10.5	117	103	168	144	1680	1568	1867	1809
1.5	1.7	0.7	3.3	28	33	10	50	2202	2013	3016	1879
6.1	6.0	8.9	8.0	85	85	115	107	877	806	540	531
19.0	19.0	19.0	19.0	244	244	244	244	1730	1730	1730	1730

Table 20: Impact per scenario

CO2e	MJ	Cal
34.6	475	6489
33.6	464	6118
41.3	537	7153
40.9	545	5949

Table 21: Weighted impact

CO2e	MJ	Cal
37	503	6491

Step 5: Comparing impact of interventions

In the last step, a set of six exemplary mobility solutions (Table 22) was collected and divided into pull and push interventions.

Table 22: Set of pull and push interventions

PULL (Incentives / Carrots)	PUSH (Penalty / Sticks)
PULL.1: On demand shuttles	PUSH.1: Speed reduction
PULL.2: Dedicated cycle lanes	PUSH.2: Parking restrictions/reduction
PULL.3: Sustainable mobility campaigns	PUSH.3: Car-free/low emissions zones

Using the earlier approach, we can quantify the potential impact of each of the interventions on the modal share per persona and scenario, and thus the respective impacts. We performed this impact assessment via a collaborative and rated the impact by intervention, scenario, and persona, measured +/- 0, +/- 1, and +/-2. Table 23 shows the outcomes of this assessment for the pull intervention of a Mobility on Demand service. For example, Rui has no reason to use Mobility on Demand and is not affected by the solution. On the other hand, Thierry has the resources and conditions to use them and thus has positive values across scenarios. More dense scenarios require fewer long trips and consequently have +1 instead of +2.

Table 23: Assumed impact of intervention 'On demand shuttles per mode/scenario/persona

	Thierry				Rui				Adrian				Jacqueline			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
Mobility on Demand (MoD)	2	1	2	1	0	0	0	0	1	1	1	1	1	1	1	1
Car	0	0	0	0	0	0	0	0	-1	-1	0	-1	0	0	0	0
Bike	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	-1	0
Walk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Micromobility (MM)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

	Thierry				Rui				Adrian				Jacqueline			
	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4	S1	S2	S3	S4
PT-MOD	2	1	1	2	0	0	1	0	1	1	0	1	0	0	0	1
PT-Bike	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PT-Walk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
PT-MM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MoD-Walk	1	2	0	1	0	0	0	0	1	2	1	0	1	2	0	2
MoD-MM	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Car-Walk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
MM-Walk	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

A cost-benefit approach could be utilised to estimate the effort expressed in cost for each intervention, allowing further to distinguish between no regrets, low regrets, and other strategies. No regret refers to interventions which have no negative impact and low/no costs. In the case of the scenario-based approach, this refers to those which have a neutral or positive effect across each of the scenarios. Low regret refers to either no/low costs with predominantly neutral or positive impacts, or medium costs with consistently positive impact. Other intervention strategies are those that have divergent characteristics across scenarios/persona groups. The integration thereof is considered as one potential extension.

Digital version of decision support tool

The above-described process contains qualitative elements, such as the scenario development or the persona creation. Yet, the subsequent impact assessment is fully quantitative, allowing for a digitally supported process. Therefore, a *browser-based prototype* was created to replicate the decision and design support process. It resulted in a Python-based browser interface that allows iterative inputs to replicate the scenario-based impact assessment process. Figure 46 shows a screenshot of the input mask as well as a link to an operational prototype. While mostly prefilled with the above-described sample data, the number of scenarios and personas, as well as all parameters can be modified. The process could be further expanded with more detailed parameters, more scenarios, and/or more detailed personas. In every step, the exemplary values reference in the process above are the base parameters.

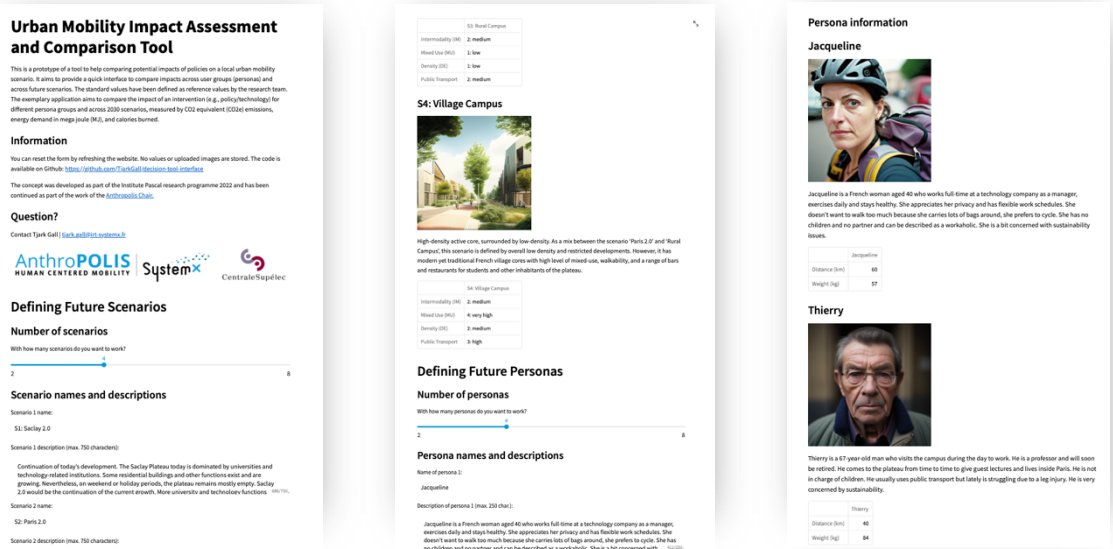


Figure 46: Screenshots of graphical interface prototype (urban-framework.com/scenario-tool; CC BY 4.0)

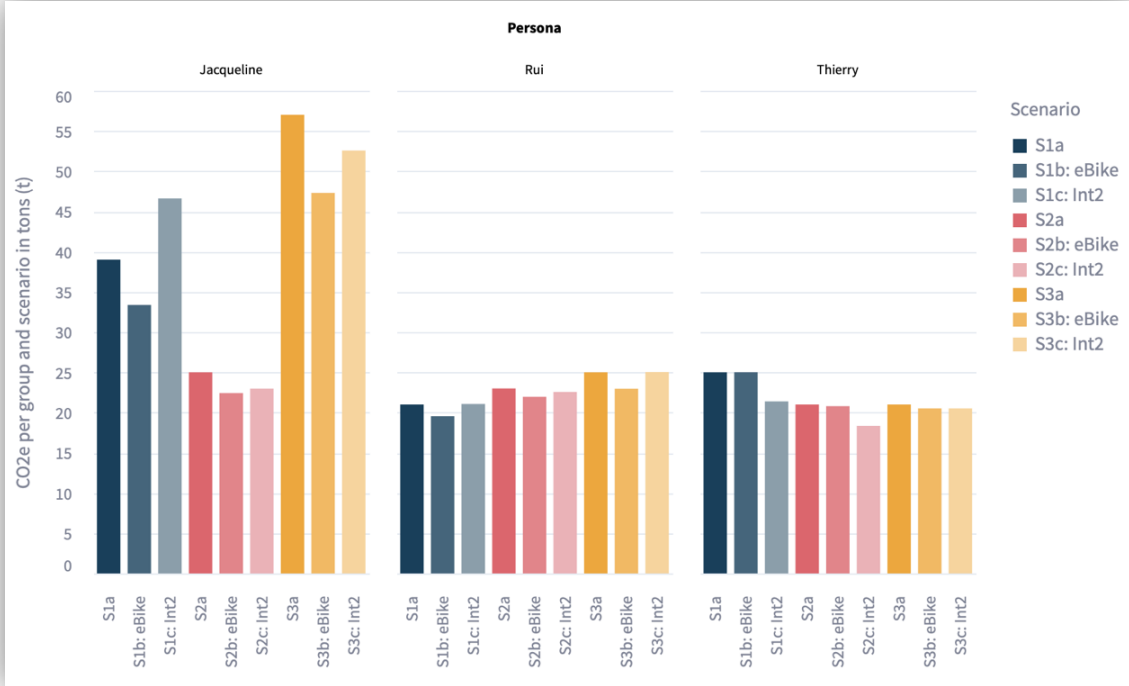


Figure 47: Screenshot showing exemplary charts of aggregated emissions per persona and scenario per day without intervention and with two potential interventions (CC BY 4.0)

Validation of decision support tool

The objectives behind the tool are threefold: 1) Foremost, it shall make scenario-based thinking – or futures literacy – more accessible in decision-making and design processes, especially in multidisciplinary teams. 2) It shall support rapid impact assessments in collaborative settings, for example, of a task group within a public sector institution. 3) The use of personas shall permit a more people-centred approach by highlighting different contributions and impacts per user group. We hypothesised that the tool has a positive effect on each of these three objectives and designed a validation approach to test this. The approach consists of three stages:

1. The tool was tested with three individuals who are familiar with the research topic and have been involved in the early development process.
2. Their feedback was integrated into a second version which was tested in two workshops with five academic participants with different profiles. An iteration between the first and second workshop permitted to adapt the tool further, as well as the provided inputs and prompts during the exercise.
3. Finally, the tool was sent together with a short introductory video and a survey to selected three experts who could not participate in the in-person validation workshop. Throughout this process, the tool has been tested by 16 people. The validation workshop design and its descriptions can be found in Annex AN.3.11.

In this section, we focus on key observations and synthesised feedback. Additionally, a large number of detailed recommendations regarding functions, interface, and extensions were collected. These will be considered for future versions of the tool.

From an overall perspective, the tool has proved to be effective in regard to all tree hypotheses which will be discussed individually in the next paragraph. In general, it was appreciated that the process was *understandable and modifiable* compared to common ‘black box’ approaches. On the other hand, it was considered a challenge to balance between different levels of information depth. For example, for mobility experts who participated in the workshops, more information and detail in the parameter setting was expressed as need. For users from disciplines other than mobility, the level of information was already too high. In the version for the second workshop, this critique was partially addressed by permitting to show and hide different elements. This could be developed further.

A similar overall discussion took place regarding the type of information provided. For example, mobility experts focused mostly on number of kilometres or mode efficiencies while economists wanted more details on the utility and financial resources of the users. Without claiming that a tool would be possible that fulfils everyone’s needs, we postulate that through further extension and options for individualisation to different use cases and user groups, a more successful exchange and assessment could be enabled. Lastly, it has been repeatedly highlighted that as the scenarios and personas are at the core of the approach, a detailed description of their creation must be made available.

Aside from the overall findings, the three hypotheses could all be, at least partially, confirmed. The first hypothesis is on the improved access to futures literacy. Throughout the discussions and exercises of the workshops, the scenarios, via descriptions, visuals, and their assigned characteristics (i.e., the level of mixed use) stimulated the exchanges and integrated the *increased uncertainty* in the discussion. The quantified representation of the resulting differences between the scenarios highlighted at the end the impact of the uncertainties. While no significant learning process could be consistently measured during the short workshops, a strong agreement on the utility of the approach to consider uncertainty resulted. In conclusion, the tool enables to easily integrate foresight in assessment and decision-making processes but in its current form did not have a significant effect on futures literacy on the validation activity subjects.

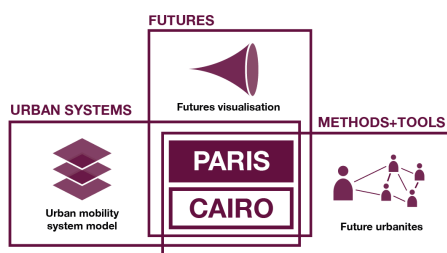
The second hypothesis is that the tool supports rapid impact assessments in collaborative settings, for example, of a task group within a public sector institution. This has been proven primarily in the second workshop where a clear task has been given to a team of researchers who took on their respective role (i.e., public policy

experts, mobility solution designer, simulation expert, economist). The task was, as a multidisciplinary team working towards more sustainable and healthy mobility in Paris-Saclay, to perform a rapid assessment if a potential mobility solution (shared automated electric vehicle) contributes significantly and positively to key performance indicators (e.g., emissions, active mobility).

The tool permitted the ad hoc task force to evaluate the fictive potential use case while considering different future uncertainties and user needs, concluding collaboratively that the solution does not positively respond to their objectives of developing a sustainable local urban mobility supply. The tool permitted to include different perspectives and knowledge and reach a joint decision.

Finally, the use of personas was hypothesised to permit a more people-centred approach by highlighting different contributions and impacts per user group. This has been confirmed throughout all validation activities and has been positively highlighted by all profiles of users. Advantages were identified at the consideration of users different to ‘us’ and the persona-per-persona discussion which highlights that some people are not or even negatively affected by a solution that shall resolve an issue. Finally, the combination of persona impacts, and occurrence permitted to target primarily those, for example, most permitting or with least access.

5.1.4 Discussion of Paris case and conclusion



This first application case study set out to test and apply the developed methodological framework to a multi-step approach of integrating future uncertainties in the design and decision-making processes of complex urban mobility systems.

After defining the UMSs and localising scenarios, we applied the method to agent-based mobility simulations at the scale of the Île-de-France region with a zoom in on Paris-Saclay. Aside from the present simulation, four 2030 scenarios were simulated without and with Shared Automatised Electric Vehicles (SAEV) introduced in Paris-Saclay. Making use of a multi-dimensional impact assessment approach, we compared key indicators across scenarios and personas: CO2 equivalent emissions, time and duration spent with mobility per day, and mobility-related expenses.

We argue that this approach has the *potential to integrate qualitative uncertainty in a structured and logical manner without making the process too resource demanding*. A few findings are important to point out and are probably not limited to this specific case. While the SAEV service shows a positive impact throughout, the differences between scenarios are by far the strongest difference, followed by improvements of vehicle efficiency. It is, therefore, important to keep the magnitude of impact in mind. This means that behavioural and social-practice-oriented measure, such as awareness or nudging campaign might bear a higher potential impact than techno-centric solutions (cf. Dyson and Sutherland, 2021). In continuation of this approach, we argue that more targeted policymaking could be enabled through the personas,

by identifying, for example, high polluters or groups that are particularly negatively affected by, e.g., higher costs or longer commuting times.³⁴

Some limitations specific to this application case remain. The *focus of the quantitative analysis should not be on the absolute numbers due to the high number of assumptions*. Instead, the method predominantly benefits comparative situations. For example, comparing mobility service solutions against each other, across scenarios, or against not having them.

On the computational side, it must be noted that agent-based simulations, in particular those of the more complex demand-responsive transport module used for the SAEV simulations, are computationally intensive. This comes with two direct limitations. First, the long running time of each scenario leads to limited possibilities of testing various constellations, for example different fleet sizes, passenger capacities or public transport schedules across multiple scenarios. Further, more detailed sensitivity analyses could increase the robustness of the approach with more resources or improved efficiently that makes this probably possible in the near future. This could be particularly interesting for cost, emission, or choice model variations. The second limitation is that the simulations have been run with to 1% down-sampled synthetic populations for efficiency purposes. We assume to have generated useful comparative values but highlight the potential improvement of accuracy when increasing the percentage as much as possible.

Further, smaller technical improvements could detail the results further and should be considered in future works. For example, considering the number of passengers in individual and shared vehicles for more detailed emissions calculations. Further, empty rides of SAEVs to rebalance the fleet or pick-up passengers are not yet considered in calculations. Lastly, for the simulations, we only looked at one possible future urban mobility intervention, namely the introduction of SAEVs. The method becomes more interesting when comparing different options of the same solution, e.g., different fleet sizes, or comparing different solutions, e.g., SAEVs versus an increased regular line bus service. The activity-based simulation approach further permits to study interactions between modes. For example, if two new mobility services are tested concurrently, they are competing for users and thus have a dynamic interaction that can be simulated (such comparison is part of the Cairo case study).

With added information on the initial and operating costs of such solutions, it would permit to make cost efficiency comparisons, e.g., to answer to questions of what the CO₂e reduction per euro is for alternative service options or solutions, or what the payback period for different services would be across scenarios. Nevertheless, this application case showed that the proposed methodological framework can support the design and decision-making process in the urban mobility context by improving the quality of agent-based simulations and increasing awareness of people-specific differences and future uncertainties.

On the other hand, the persona-based digital decision support tool, even if just explored with few personas and scenarios, proved the potential to include and *consider various types of users and scenarios*. The pre-filled, digital interface

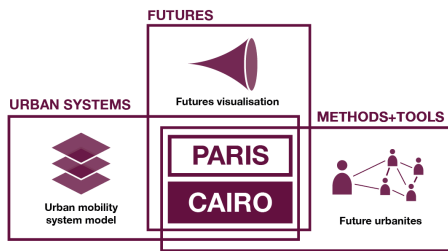
³⁴ It is important to reiterate that small groups might be incorporated into more heterogenous groups due to small sizes. Thus, depending on the application, manual adaptation or complementing of the set of personas might be necessary.

prototype helps to co-elaborate different intervention strategies and quantify potential positive and negative impacts thereof across potential futures and groups of urban mobility users. While the focus was not on setting most adequate values, we can still observe interesting behaviours resulting from the use of the tool. For example, users do not assume certain personas to change much across scenarios due to existing constraints while others are much more likely to adapt to its contexts. Further, some people produce much more emissions than others, yet are in some cases less numerous and thus have a nearly negligible impact. Further, certain interventions could be very cheap to implement with high expected potential positive impacts for identified target groups while others seem difficult to justify. Most importantly, the tool is *non-normative* and instead has a clear goal to contribute to informed decision-making. Compared with black box approaches, every step is explained, accessible, and can be modified. Even if this comes at the cost of a simplified interface, we argue that this can be a justifiable compromise to ensure an increased explicability of technological approaches. Finally, we imagine as potential use cases not only to make impact estimations but also to explore individually complex relationships and the magnitude of certain changes (e.g., a 10 g/km emission reduction) as well as to stimulate interdisciplinary discussions and exchanges in workshop or capacity development contexts.

Despite a range of limitations and potential future extensions, this case study applied the methodological framework and successfully tested a set of methods integrating uncertainty. The combined use of the support tool and the agent-based simulation permits *an open and replicable design support workflow with different levels of complexity and output detail and accuracy*. The next sub-chapter attempts to replicate and validate some of the core components and extend the method in identified priority areas.

5.2 Validation of design support methods in Cairo

Research question	How can design processes of people-centred mobility solutions for the future urban system of Cairo be supported?
Methodology	Mixed-method case study, using qualitative (i.e., interviews, workshops) and quantitative methods (i.e., k-proto clustering, agent-based simulation).
Results	A set of localised urban mobility scenarios and synthetic populations as intermediary design objects. The successful replication of the method to compare and assess potential urban mobility interventions in local context while integrating uncertainties.
Contributions	<ul style="list-style-type: none"> a) Replication of method for localising scenarios. b) Replication of method for integrating scenarios in agent-based simulation.
Implications	Practical implications of this sub-chapter include the localisation of scenarios, the use of the created and accessible intermediary design objects, as well as the structured integration of future uncertainties on the people-layer in agent-based simulations. The synthetic population generation and simulation processes are fully replicable and currently tested and extended, as well as considered for future projects by collaborators in Egypt. Within methodological limitations, the results of the simulated scenarios can inform policymaking and planning and will be published and presented to inform the current discourse.



This section has a dual purpose. Foremost, it aims to replicate the developed methodological framework in another, highly heterogenous context. Secondly, the objective is to contribute simultaneously to the local urban research and planning community and provide initial results that bear potentials to inform planning and design

decisions. We develop and run agent-based urban mobility system simulations of Greater Cairo today and for four 2030 scenarios. For the latter, we analyse system impacts of three possible urban mobility solutions. These interventions are Bus Rapid Transit (BRT), better walkability around stations, and improved intermodality.

This sub-chapter came to light due to the welcoming and open minds of Prof Dr Nabil Mohareb and Dr Sherif Goubran at the American University in Cairo and Mohamed Hegazy, Abdelrahman Melegy, and Hazem Fahmi at Transport for Cairo (TFC). The work presented here has been developed in collaboration with them. The ideation of potential interventions has been a joint activity. Hazem Fahmi (TFC) contributed significantly by generating the probably most detailed activity location database for Greater Cairo. Dr Sebastian Hörl of IRT SystemX integrated the different components in the existing pipeline of MATSim. Dr Tarek Chouaki provided technical support and advice in the simulation process and parameter adaptations for the interventions.

It copies the structure of the preceding sub-chapter by starting with the case study description, followed by the scenario localisation and future synthetic population generation, a comparative assessment of interventions, and the conclusion and discussion of the method. The majority of data is open access, and the methods are either already publicly accessible via public source code repositories or will be in the near future.

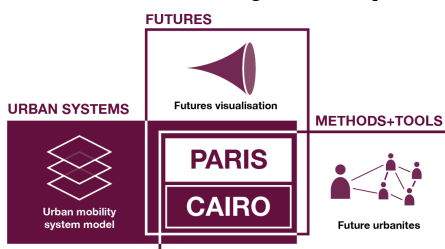
Data and source code

With the limitation of one dataset that can be requested, all data is open source, and the process is replicable.

Data preparation process: <https://github.com/TjarkGall/cairo-synthetic-population-preparation>

Implementation in existing MATSim pipeline: <https://github.com/eqasim-org/ile-de-france/blob/cairo/docs/cases/cairo.md>

5.2.1 Case study description of Cairo



This section describes the context of the second case study. Compared to the previous part on Paris which is both the primary focus and context to discuss various general developments, this section aims to introduce only key elements of Cairo as well as local specificities.

Before crossing the Mediterranean Sea, a few words on the choice of the case study. Mobility studies in primary cities in Northern America and Western Europe are still dominating scientific discourse. This focus is understandable as Western cities are

the location where large part of global emissions are created, promising solutions developed and tested, and socio-spatial inequalities still highly prevalent. On the other hand, cities primarily in Africa and Asia are home to most of today and tomorrow's population growth, experience ongoing urbanisation, oftentimes import higher polluting vehicles banned from Western markets, as well as being plagued by much higher mobility injustices due to the cities sheer size, pace of growth, and 'informal' developments.

This, combined with the ambition to test the developed method in a context with less available data, led to the decision to *add a second case study of a megapolitan urban area with complex and different mobility system components*. Combined with the requirement to easily access local expertise, the choice fell quickly on Cairo and the American University in Cairo (AUC) and Transport for Cairo (TFC) as dual hosting setup. AUC permitted access to the largest English-language library in the region, various other resources, and the supporting network and infrastructure of a leading global university. The expertise on urban design and planning in the region and climate enriched the elaboration of diverse place-based interventions in the urban mobility system. The second partner, TFC, is a strategic advisory practice working on multiple large-scale mobility and transport projects in Egypt and internationally. Among others, TFC digitised the multiple public transport offers to feed them into route-planning platforms and conducted the most extensive mobility origin-destination and travel interviews in Cairo. Together with an open access approach exemplified in a public GeoPortal³⁵ and an interest to co-create a workflow for agent-based simulations of scenarios at the Greater Cairo level, the two partner organisations play a crucial role through their expertise and complementarity.

Building on this, the sub-chapter is organised in three sections. First, the UMS layer of people is used to introduce socio-demographics of Cairo. Next, a focus is on the infrastructure by using three highly inter-connected topics: Desert New Towns, the housing market, and informality vs. modernism. These three in combination are the driving force for the spatial structure of Cairo today, as well as the planning of major mobility infrastructures and services. Finally, the mobility services in Cairo are introduced with a focus on different more-or-less formal modes of mobility, as well as some quantitative insights on modal shares, socio-economic mode choice determinants, and dominant pain points in the present.

5.2.1.1 People of Cairo

Cairo, the capital city of Egypt, has a rich long history that spans roughly as that of Paris as a city and much older artefacts such as the Pyramids of Giza. The city's origins itself can be traced back to the Roman period, around 30 BCE when it was known as Babylon-in-Egypt. However, it was during the Islamic era that Cairo flourished and became a prominent centre of culture, trade, and scholarship.

In the 9th century, the Abbasid Caliphate established the city of Al-Qahira (القاهرة, EN: The Victorious) on the eastern bank of the Nile River. Under the Fatimid dynasty in the 10th century, Cairo became the political and cultural centre of the Islamic world. It was during this period that iconic landmarks like the Al-Azhar Mosque and the Al-Hakim Mosque were built. Cairo continued to prosper under various dynasties,

³⁵ <https://data.transportforcairo.com> [accessed 8 July 2023]

including the Ayyubids, Mamluks, and Ottomans, who left their architectural and cultural imprints on the city.

In the 19th century, Egypt fell under British occupation, and Cairo became a hub for political and nationalist movements striving for independence. Finally, in 1952, Egypt gained its independence, and Cairo became the capital of the newly established Republic of Egypt but has been significantly impacted by the Arab spring and regular political unrests. In recent times, Cairo has experienced rapid urbanisation and population growth, resulting in modern infrastructure, bustling neighbourhoods, and a vibrant cultural scene. The city remains a significant centre for politics, economy, and tourism in the Middle East, exemplified by, for example, hosting the next World Urban Forum in 2024.

The current population of Greater Cairo is estimated at about 22 M³⁶, resulting from ongoing natural growth and rural-urban migration as well as from other towns. A significant part of the population is under 30 years old and disadvantaged due to limited access to opportunity, education, and health care (Sims, 2012).

5.2.1.2 Infrastructures of Cairo

The spatial structure of Cairo is defined by a complex overlay of several millennia of human settlements, incorporating the pyramids of Giza (~2,500 BC), Persian settlements (~600 BC), the Babylon Fortress (~30 BC), and a claimed resting place in Coptic Cairo during Maria and Joseph's flight into Egypt. Since the end of the first millennium AD, Cairo became an important home for Islam, followed by Mamluk and Ottoman dynasties, interrupted by a short Napoleonic conquest, until the British occupation which ended in 1956. Without attempting to provide a complete overview, a few key elements are described below. For further details on recent history, we refer to Sims's book 'Understanding Cairo' (2012). Figure 48 shows a map of what we consider here as Greater Cairo, even if no fixed geographical or administrative entity. Key elements are the Nile that passes from the South to the North and provided the lifeline for most of the historic settlements. On the western side is the Giza Governate, on the east the Cairo Governate, together constituting the majority of Greater Cairo. The city centre is made up of the famous Tahrir Square, Downtown Cairo, Islamic Cairo, among others. West of it are the Pyramids of Giza which were secluded in the desert but have been mostly enclosed by the urban expansion over the past century.

³⁶ <https://www.macrotrends.net/cities/22812/cairo/population> [accessed 1 August 2023]

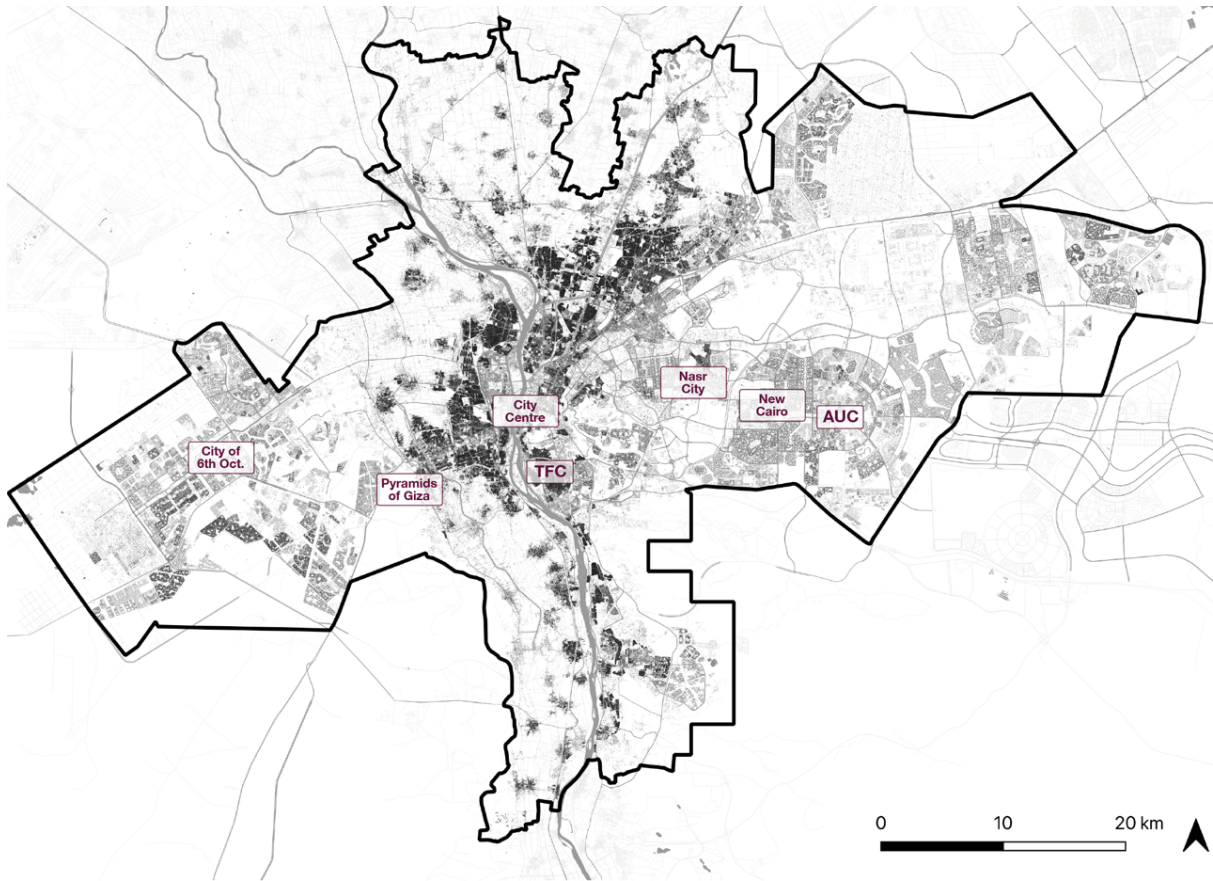


Figure 48: Map of Greater Cairo with highlighted areas (Data sources: Streets/water from OSM, Buildings from Google Open Buildings and OSM addresses, Outline from TFC)

The central components of Cairo's recent past are new towns which are carved out of the desert due to need for space, evolving abilities of infrastructure development, and economic interests (GOPP, 2012; Sims, 2018). On the map, a few selected ones are shown. Nasr City is one of the oldest new towns which came to light in the 1960s. The City of 6th October – named after the starting date of the Arab-Israeli war in 1973 – was founded in the late 1970s in the western desert. Within limitations, these two are commonly referred to as the most successful ones compared to many projects which never realised as intended (The Aga Khan Award for Architecture, 1984; Sims, 2018; JICA, 2007; Mahmoud and Rashed, 2016; Angéilil and Malterre-Barthes, 2018). One of the largest and more recent projects is that of New Cairo, situated in the east of the defined area for Greater Cairo. Its area is about twice of that of Paris, yet with widespread vacancy, systemic real estate speculation, and a population density about 15 times lower.

Many developments are still ongoing, new mass transit is constructed, and the New Administrative Capital currently being built on its other side (its street layout is already visible outside the study area in the lower east in Figure 48). However, at the current state, New Cairo belongs to the long list of new town developments that have not fulfilled their objectives but instead rather intensified congestion, gentrification, and socio-spatial inequalities (Abdeldayem and El-Khouly, 2020; Farid and El Shafie, 2002; Mahmoud, 2017).

A significant driver and constituent of Cairo's growth and the escape in the surrounding desert relates to housing. Very dense traditional as well as self-planned³⁷ and unregulated settlements arose throughout the metropolitan area and constitute housing solutions for the majority of Cairo's population. Yet, with the highest global densities of up to 300k/sqkm (TFC, 2021) – only beaten by the now destroyed Kowloon Walled City in Hong Kong – many of these areas have restricted access to sanitation, fresh air, sunlight, and other infrastructures and basic services (Shawkat, 2020).

One of the responses is the construction of new towns which are used as to relocate people from areas defined as inadequate or as potential areas for new developments. Yet, the success thereof is hindered by a mix of international investment and speculation in the property market enabled by the literal creation of value out of sand (Hafez, 2017), the dominant middle and upper class settlement typologies of gated community as new optimal model (Almatarneh, 2013) with complex challenges for sustainability (Metwally and Abdalla, 2013), and the cultural dimension which leads to families buying sometimes remote apartments for their sons to increase their chances during spouse search (Shawkat, 2020). The consequences are plenty: Commutes become longer, more expensive and difficult while traffic and grid locks multiply. Low densities hinder the development of an acceptable level of public transport supply. Relocated families are disconnected from economic opportunities and social networks and might move back to inner self-planned settlements.

This dynamic is representative with a larger rivalry between tradition and modernism that can be observed in Egypt across politics, religion, society, and urban development. The modern style of life implies a car and a house with a garden. The global effect of the American Dream, in this case rather transferred via the proxy of highly developed Arab cities such as Dubai, Abu Dhabi, Kuwait City, or Doha. The past and indirectly the self-planned areas are associated with high levels of air pollution, backwardness, and a lower quality of life, leading to persisting sprawl, relocations, and increasing homogenous socio-economic enclaves and gated communities (Singerman, 2011; Ashoub and ElKhateeb, 2021). On the other hand, the central areas are home to complex socio-spatial and economic dynamics which are beneficial to or even the basis for the livelihood of a large part of Cairo's population (Sims, 2012; Mohareb, 2009a-b, 2016, Singerman and Amar, 2006).

5.2.1.3 *Mobility services of Cairo*

The 22 M people must be able to move both within and between the world's densest neighbourhoods and between the desert new town extremities, spanning up to 90 km (about the distance between Paris and Rouen), additional to many who are travelling to Cairo from elsewhere for administrative duties, commerce, or in search for economic opportunity. Logically, this comes with significant challenges regarding spatial and economic accessibility (Kalila, 2019), the ability to use services such as public parks (Mohamed et al., 2022) and various behavioural changes mostly in new towns such as only walking in limited manner with impacts on health and well-being (Mohareb, 2022). A complex ecosystem of stakeholders and projects aims to tackle

³⁷ Various terms refer to organic and mostly unregulated settlements: Now derogatory terms like favelas and slums, unplanned settlements wrongfully implying that no planning takes place if not done by the formal public sector, or most commonly informal settlements which while referring primarily to the informal land use rights, however, have as consequence that also the people and their rights are seen as informal. The term self-planned shall obviate this.

some of these issues, guided by the national government via guiding policies such as the 2030 Egypt Vision (GoE, 2016). The primary involved stakeholders include the Cairo Transport Authority (CTA) as main bus operator with private operators running minibuses via concessions. The Ministry of Transport is responsible for Greater Cairo, the Egyptian Company for Metro Management and Operation (ECM) for the metros, overall construction through the National Authority for Tunnel (NAT), and the Egyptian National Railways (ENR) for the rail lines. The Greater Cairo Transport Regulatory Authority (GCTRA) has the regulatory responsibility (Abdalla and Ferro, 2017). Other private operators are complementing the transport supply leading to large number of operators, routes, and transport fares (UITP, 2020a).

A number of modes come together in this context. Foremost, paratransit modes, buses, shared taxis and normal taxis constitute about 83% of motorised trips (Abdalla and Ferro, 2017). These include licensed and unlicensed *vans* with seven seats (maximum for unlicensed ones due to regulatory seat limit of maximum seven), *microbuses* with 14 seats, *minibuses* with 29 seats, normal *buses* mostly operated by CTA with 49 seats, private ride hailing networks, and private-operator high quality buses for longer distances (e.g., Mwasalat Misr). Bus prices vary between €0.1 and €1 which are for lower income groups sometimes enough to exclude certain modes (TFC, 2021). TFC recently digitised public transport supply via geo-referenced data collection and deducting stops based on accumulation of stops in one location, and thus digitising the intrinsic knowledge of paratransit drivers and regular users, making the use of paratransit now possible via online routing tools such as Google Maps (TFC, 2021).

These buses are complemented by increasingly banned free-floating tuk-tuks³⁸ and some micro-mobility services limited to central areas and gated communities. While the last tram stopped operating in 2019 – not without protest – the metro operates since 1987 and expands constantly (TFC, 2021, UITP, 2019), has high passenger numbers including from the middle class and recovered despite significant losses during the Covid-19 pandemic (UITP, 2020b). During my research stay in late 2022, a new bike-sharing service was inaugurated in Downtown Cairo by the Cairo Governate in collaboration with UN-Habitat, ITDP, and the Swiss Drosos Foundation, together with some first bike lanes created overnight.³⁹

Existing metro lines 1-3 are still being expanded, e.g., with another critical part of line 3 inaugurated in October 2022, while new metro lines are planned, in strong collaboration with the French development bank and private transport companies. Additionally, a high-capacity monorail is in construction connecting (with interruption bridged via the metro) the City of 6th of October and New Cairo, and one day probably the New Administrative Capital, and a high-speed electric train shall connect the Western and Eastern parts via a reversed arc passing south of central Cairo. Other mass transit projects including a Bus Rapid Transit (BRT) project are discussed or ongoing, with varying levels of maturity and completion (TFC, 2019; Abdalla and Ferro, 2017). Finally, the electrification of mobility becomes a more frequent discussion topic, recently pushed due to the purchase of many electric busses as temporary shuttles during the COP27, and a range of smaller vehicles including two- and three-

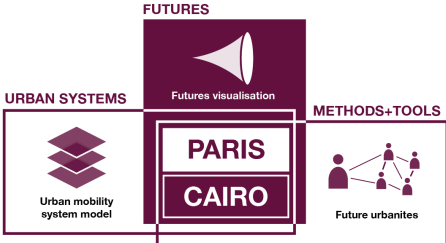
³⁸ <https://egyptindependent.com/tuk-tuks-officially-banned-in-new-cairo/> [accessed 1 August 2023]

³⁹ <https://www.itdp.org/2022/10/20/cairo-bikeshare-cycling-momentum-in-africa/> [accessed 1 August 2023]

wheelers with an estimated potential for significant emission and pollution reduction (CEDARE, 2018).

This completes the short outline of the UMS of Cairo, providing a glimpse on some of the key components of people, infrastructures, and services. The next section uses this model to create and localise a set of future scenarios in Cairo.

5.2.2 Localisation of scenarios in Cairo



Additional to desk research, a literature review, over 20 unstructured expert interviews lasting 30 minutes to two hours, site visits and observations during the research visit, a workshop organised with local mobility and urban planning experts is the core contributor to the co-creation of local urban mobility scenarios. The workshop targeted primarily the

validation of intermediary design objects and workshop tools, such as the futures cone, the distinction between trends and uncertainties, and secondly the joint elaboration of different uncertainties and their spatial manifestation in specific local contexts in Cairo (Figure 49, description in Annex AN.3.9).



Figure 49: One of two workshop groups discussing the localisation of uncertainties (October 2022)

Two groups of six to seven people worked on the localisation of trends and uncertainties in a specific spatial context in inner Cairo. The uncertainties compiled and discussed are the development of non-motorised modes, travel demand, population density and reallocation, overall demographic shift, user culture, and recharging infrastructure. A follow-up survey⁴⁰ was conducted with participants and

⁴⁰ The details of the survey can be found in Annex AN.7.2.

other experts who could not participate – the day of the workshop was one of the few rainy days leading to floods on major infrastructure connections and a near-total gridlock.

15 experts participated at the survey of whom eight were present at the workshop as well. Ten were under 35 years old and all were either researcher or practitioner in the urban planning or mobility context. Seven respondents use public transport more than ten times per month, the rest less than ten times. A set of provided trends and uncertainties were ranked on likelihood and importance. While the sample size is too small to make quantitative deductions, expert opinions are very homogenous and in line with expectations resulting from interviews, workshop, observation, and literature. In Table 10 and Table 11, we list the *trends and uncertainties* organised by the aggregated ranking of likelihood with an indication in the second column of their perceived importance.

Table 24: Future trends for Cairo 2030, ranked by sum of perceived likelihood and importance

Trends	Likelihood	Importance
<i>Continued population growth: Continuing growth to over 25 million by 2030</i>	1 (highest)	1 (highest)
<i>Urbanisation: More and more people living in or around urban and metropolitan centres</i>	2	3
Digitalisation: Technology being more widespread across sectors and more people using it on a regular basis	4	4
Mass transit: Expansion of the rail-based public transport system	6	2
Climate crises: Climate change leading to increasingly frequent and intense disasters or extreme events, such as heat waves	3	7 (lowest)
Aging population: An aging population requiring adapted solutions and a younger population more likely to embrace new mobility options	5	6
Growing middle class: Growing middle class driven by economic growth and the expansion of education and employment opportunities	7 (lowest)	5

The prompts were: Please rank the following trends on their likelihood, meaning which will most likely realise in Cairo (options: Not likely at all, Not likely, Likely, Very likely). Please rank the following trends on their importance, meaning which will impact urban mobility in Cairo the most (options: Not important at all, Not important, Important, Very important)

Table 25: Future uncertainties for Cairo 2030, ranked first by likelihood and perceived importance second

Uncertainties	Likelihood	Importance
<i>Development of the housing market: E.g., continued urban sprawl and new towns or densification and infill</i>	1 (highest)	2
New mobility solutions: E.g., Bus Rapid Transit (BRT), (trackless) trams, modern busses, and autonomous shuttles	2	1 (highest)
<i>Private car ownership: Continuation of rise of car ownership or stagnation</i>	3	4
Shared mobility: E.g., car-, bike-, ride-sharing, and other shared mobility services, such as micro-mobility	4	3
Integrated multi-modal transportation: E.g., allowing people to switch between different modes of transport quickly and easily	5	6
Active mobility: E.g., walking and cycling as transport mode across different societal sectors, expansion of the bike-friendly infrastructure	6	5
15-minute city: E.g., mixed-use urban villages	7	7

Adoption of low-emission vehicles: E.g., electric cars, hybrid vehicles, and alternative fuel vehicles 8 (lowest) 8 (lowest)

The prompts were: Please rank the following uncertainties on their likelihood, meaning which will most likely impact urban mobility in Cairo (options: Not likely at all, Not likely, Likely, Very likely). Please rank the following uncertainties on their importance, meaning which might impact urban mobility in Cairo the most (options: Not important at all, Not important, Important, Very important)

This leaves us with a strong trend of *continuous population growth* both via natural growth and migration/urbanisation, and two secondary trends of *digitalisation and increasing mass transit expansion*. These are development to be used for all four scenarios and assumed as very probable developments. With average growth rates of about 2% over the past years, we assume a population increased from 22 to 25.5 M by 2030⁴¹. Where this growth will take place depends on the one of the uncertainties and will be discussed in a bit. The digitalisation acts as a larger support trend while the expansion of mass transit means that we assume for 2030 the completion of several currently ongoing or planned rail-based public transport projects, notably the metro line extensions, the monorail, as well as the high-speed connector in the south.

For the uncertainties, we can assume the *level of car ownership* as middle-class proxy uncertainty which was questioned as a trend. Some other uncertainties originate directly from the mobility context and can thus be seen as possible solutions to be tested (see Chapter 5.6), namely new mobility solutions as Bus Rapid Transit (BRT) system, integrated multi-modal transportation, and active mobility. This leaves the uncertainty named *Development of the housing market: E.g., continued urban sprawl and new towns or densification and infill* as the strongest one. In this case, we have two critical uncertainties and can make use of the previously introduced 2*2 scenario grid (Rhydderch, 2017).

Table 26: 2*2 scenario matrix with critical uncertainties 'Urban development' and 'Mobility'

		Urban development	
		<i>Sprawl</i>	<i>Densification</i>
Mobility	<i>High car-ownership</i>	Scenario 1 Growth Auto-sprawl	Scenario 3 Discipline Gridlock
	<i>Low car-ownership</i>	Scenario 2 Collapse Disconnection	Scenario 4 Transform Urban revival

Making use of Dator's four archetypes Growth, Collapse, Discipline, and Transform and the secondary trends, we can supplement the four base scenarios and generate narrative descriptions and visual supports.⁴² Scenario 1 is shown below while Scenarios 2-4 can be found in Annex AN.7.2.

⁴¹ World Population Review: <https://worldpopulationreview.com/world-cities/cairo-population> [accessed 9 July 2023]

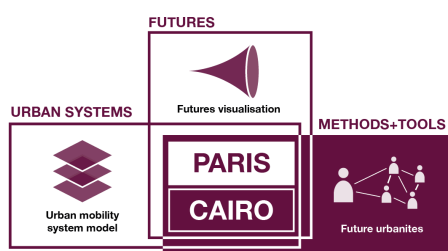
⁴² The visualisations are generated with Midjourney, using the scenarios descriptions preceded by '2030 scenario visualisation in realistic style' as prompt and conducting several iterations.

Scenario 1 | Auto-sprawl



Greater Cairo has undergone significant urban growth, accompanied by increased car ownership. Increasing sprawling residential areas have emerged, and the roads are filled with a greater number of vehicles. The government has invested in expanding road networks and implementing intelligent traffic management systems. While car ownership has risen, efforts to promote sustainable transportation include an expanded metro network and bike-sharing programs. Digitalisation plays a crucial role in managing urban growth, optimising traffic flow, and enhancing urban services. Greater Cairo strives to balance private vehicles with sustainable options, ensuring efficient mobility and improving residents' quality of life.

5.2.3 Application of scenario-based method in Cairo



The first step is to create an operational simulation of the present situation. For this, a range of data is necessary, listed Table 27. As an activity-based model, the focus is on the synthetic population and the associated activities, available modes, etc. Secondly, the underlying transport infrastructure must be known. For the latter, the street network

from OpenStreetMap (OSM) and the General Transit Feed Specification (GTFS) files by TFC are readily available.

Table 27: Data sources for present agent-based simulation of Cairo

UMS Layer	Title	Source	Status
Infrastructures	Street network	OSM	Open
Infrastructures	Building footprints	OSM	Open
Infrastructures	Building footprints	Google Open Buildings	Open
Services	GTFS	TFC	Open

UMS Layer	Title	Source	Status
People	Mobility survey	TFC	On request
People	Origin-destination survey	TFC	On request
People	Population per area	CAPMAS	Open
People	Labour Force Survey	Economic Research Forum	On request

The challenging part is the population. In its basic form, it consists of individuals including some characteristics, e.g., if they have access to a car, their home location, their activity type (e.g., home > work > leisure > home) including times or time windows, and locations of the activities in the activity chain except the home location. The process is described here only synthetically but is fully available via the referenced public online repository. The starting point was to define the geographical extent which shall be considered (dark black boundary in Figure 52). This has been defined in collaboration with mobility experts from TFC to encompass major populated areas as well as make use of the administrative boundaries of qism (قِسْم), an urban sub-unit under the governate level. The defined area contains the majority of 74 qism. Next, we used the Labour Force Survey (LFS) by the Economic Research Forum (ERF) which can be requested for academic use (ERF, 2022).

By scaling the data by its statistical weights, the data provided insights in socio-economic information by area. Combined with population density data per geographical unit⁴³, this allows to scale the *population statistically representative to an overall population of about 22.9M*.

For the data on mobility behaviour, two surveys conducted by TFC are used.⁴⁴ First, an Origin-Destination (OD) survey of about 10k entries and 2.1k travel interviews (TI). Both were collected as intercept survey at various locations throughout Greater Cairo, primarily in 2021. The OD survey contains information of what type of people move by which mode, with what trip purpose, and when from which origin to which destination. All locations were geocoded by TFC. The TI contained the same information but asked more detailed information, among others the number of trips on the previous day. This data is cleaned and filtered to only keep data entries referring to weekdays (Sunday-Thursday). Thereafter, the detailed trip information of both surveys is randomly assigned to *daily trip profiles* by matching socio-economic data. This results in a database of trip profiles (without times) with between 1 and 6 activities per day. These trip profiles are scaled up and randomly assigned to the overall population. At this stage, about 13% of the people are deleted because based on the TI, this roughly equals the number of people not moving on an average weekday.

Next, time profiles are created, making assumptions on purpose-specific trip durations and activity-based start times based on the number of activities. To avoid many trips starting at the identical time, a Monte Carlo-based approach has been used to randomly distribute activity start and end times. After filtering trip schedules with unrealistically short breaks or overlaps of activities, the remaining schedules are

⁴³ Density distribution by qism from 2017 census, accessible at: <https://www.cedejcapmas.org/> scaled up to 2021/2022 population from ERF LFS.

⁴⁴ All data by TFC is either already available on their data portal, will be made available in the near future, or is accessible on request: <https://data.transportforcairo.com/>

assigned randomly to the population based on the number of activities. The resulting movement distribution over a day (Annex AN.7.3) has been compared to existing traffic peak data but constitutes one of the areas of needed calibration if and when more data is available. This results in a population of about 15.9 M moving individuals on a normal weekday with a total of 38.2 M daily trips, or on average a bit over 2.4 trips per person per day.

Next, locations for home locations and other activities are needed. This process is divided in three parts: First, home locations were generated and assigned to the individuals based on their location. Next, activity locations are generated. Third, activity locations are assigned to each individual based on their home location and the Euclidean trip distances assigned from the OD/TI data.

For the *home location generation*, two databases are used. First, while the quality and extent of mapped buildings in OpenStreetMap is limited in Cairo, a very complete address database has been created to facilitate, for example, online delivery services. This constitutes the largest part of the home location data. On verification, some newer developments or areas are not included yet. Therefore, Google Open Buildings (GOB), a global database of remote-sensed building data, is used to supplement the address database. Buildings exist as polygons with a certain size in square metres and confidence resulting from the remote-sensing approach. We filtered buildings under 40 square metres and with a confidence of under 70% by visually comparing the results with the reality (cf. Annex AN.7.3). Centroids of the remaining GOB data are added to the address database if they are at least 50 m away from any existing address point. This results in a point database of 1.2 M entries. Maintaining the preestablished density per administrative unit, the addresses are randomly assigned to the individuals in the population.

In the second step, *activity locations* are generated. This step has been executed for this project but was led by TFC. Distributions of buildings, building units (shops, apartments, etc.) and establishments are taken from census reports⁴⁵ of CAPMAS, the Central Agency for Public Mobilization and Statistics of Egypt. Through Iterative Proportional Fitting, buildings, units, establishments were distributed. Next, buildings are matched to the OpenStreetMap address database. The output file contains work locations, secondary activities (i.e., leisure, sports, shopping), education facilities by type (i.e., elementary/secondary school, college), and universities. The database already contains information on the number of workers or pupils for institutions. This information is at the current stage not integrated in the location-assignment process.

The last step of assigning locations to the activity chains of individuals in the synthetic population is performed as part of an existing MATSim pipeline and described in detail by Balać et al. (2023). In short, an algorithm takes the trip purposes, the distances between them, and the activity locations as inputs and attempts to match them as close as possible.

After these three steps, a synthetic population based on current data has been created, including socio-economic data, home locations, a set of activities and trips with times, and possible activity locations based on distances. The above paragraphs contained many times the words random or synthesised. The process has potentials

⁴⁵ Annual Bulletin of Pre-University Education 2020/2019, Annual Bulletin of enrolled students - Faculty members 2018/2019, 2017 Census - Establishments – Cairo, 2017 Census - Establishments – Giza, 2017 Census - Establishments – Qalyubia.

for improvements at various steps – some of them already ongoing or planned. However, the resulting and replicable synthetic population appears to be the most complete – or even the only one, existing so far. It further builds on well-established methods, detailed databases, uses data that has not been available until very recently (TFC’s OD/TI and Google Open Buildings) and makes partial use of the existing synthetic population generation pipeline developed by Hörl and Balać (2021).

Finally, the requirements on the level of detail and accuracy of synthetic populations for activity-based simulations depend largely on the application. For a high-level of detail simulation analysis at a small spatial scale, the created population might not suffice yet. On the other hand, for systemic analysis and impact assessment of potential future service at metropolitan level, the level of detail should be sufficient as shown in the following paragraphs.

After feeding the synthetic population, the *street network*, and the *transport supply* via the GTFS files in existing MATSim pipelines⁴⁶, the current situation can be simulated. To reduce running times of simulations, smaller sample sizes are commonly used. Some literature suggests that 5% sample sizes are accurate for normal use cases (Llorca and Moeckel, 2019) while dynamic service modelling requires sample sizes of, in some cases, at least 65% (Kagho et al., 2022).

We ran simulations at 0.1%, 1%, and 5% for test purposes, including different number of variations. To balance between needed resources and outcomes, and considering the minimal differences we observed in the different sample sizes, we here present outcomes from 0.1% samples. Running simulations with larger samples are foreseen after more calibration work has been conducted and the quantitative outcomes become more precise aside from their comparative character as prioritised here. For the iterations, we tested a 0.1% simulation (always considering linearly scaled road capacity to model congestion) with 400 iterations and identified a strong convergence before 100 iterations (Figure 50).⁴⁷ Subsequent simulations are run with 100 iterations.

⁴⁶ Accessible here: <https://github.com/eqasim-org/ile-de-france/tree/cairo> (integrated by Sebastian Hörl)

⁴⁷ All simulations with either 100 or more iterations, consideration of congestion, or sample sizes of more than 0.1% that have been run (meaning all that are discussed in this dissertation) were run on the high-performance computing cluster shared by several universities including CentraleSupélec (<http://mesocentre.centralesupelec.fr>). A simulation with a 0.1% sample, 100 iterations, and congestion takes about 3 hours with 40 CPUs and 20 GB RAM allocated.

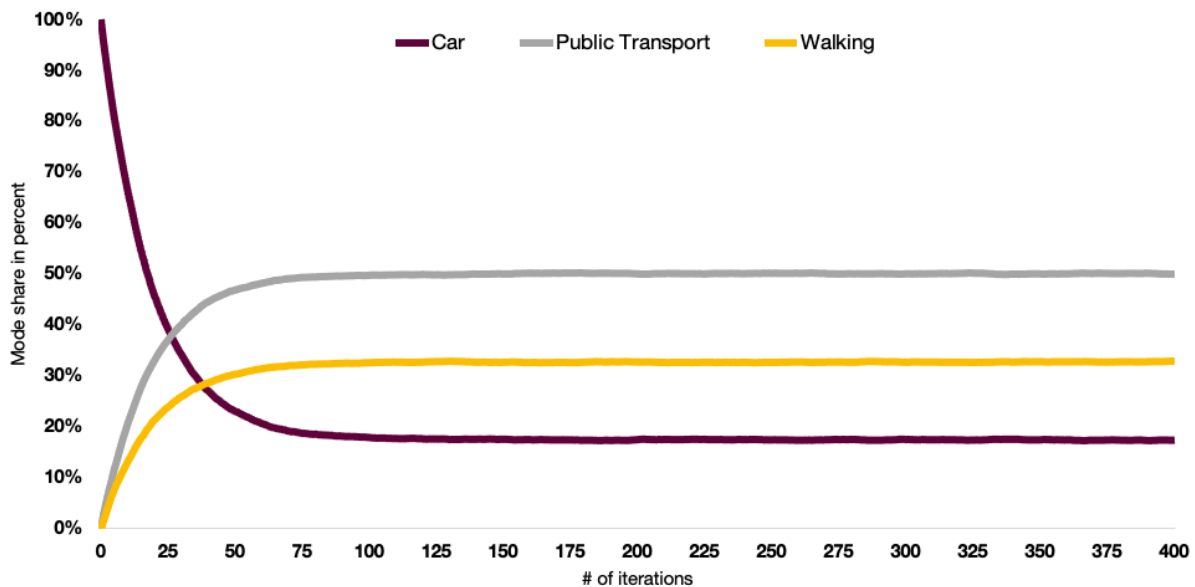


Figure 50: Graph showing mode share distribution from iteration 1 (left) to 400 (right) and a convergence before iteration 100 (CC BY 4.0)

Figure 50 shows, additional to the point of convergence, where the mode shares stabilise. At iteration 400, car use is at 17%, walking at 32% and public transport use at 50%. The average trip leg (one segment of a trip with one mode) distance is just below 4 km while average trip distances (multiple legs) are at about 12.5 km. We can further look at the cumulative kilometres disaggregated by mode. When scaled up to a 100% population, it converges at about 67 million km by car, 301 million km by public transport, and 88 million km by walking. Even if we assume a low level of GHG emissions per kilometre (150 g CO₂e per passenger kilometre (pkm)), this would result in 105,000 tons of CO₂e per day from passenger transport by car alone.

Further, we can look at the *temporal distribution for one day* (Figure 51) as well as the *spatial distribution* (Figure 52). The former shows a morning, lunch, and evening peak across modes with the most heterogenous distributions for public transport and walking trips. The second figure shows the car traffic counts with a scaled segment width based on the number of vehicles passing in one day. 9% of the public transport trip segments are made by subway and 91% by bus. The most used line is metro line

1 (4%), followed by metro line 3 (3%) and 2 (2%). These outputs inform the initial local expert-based validation of the reliability of simulation outcomes.

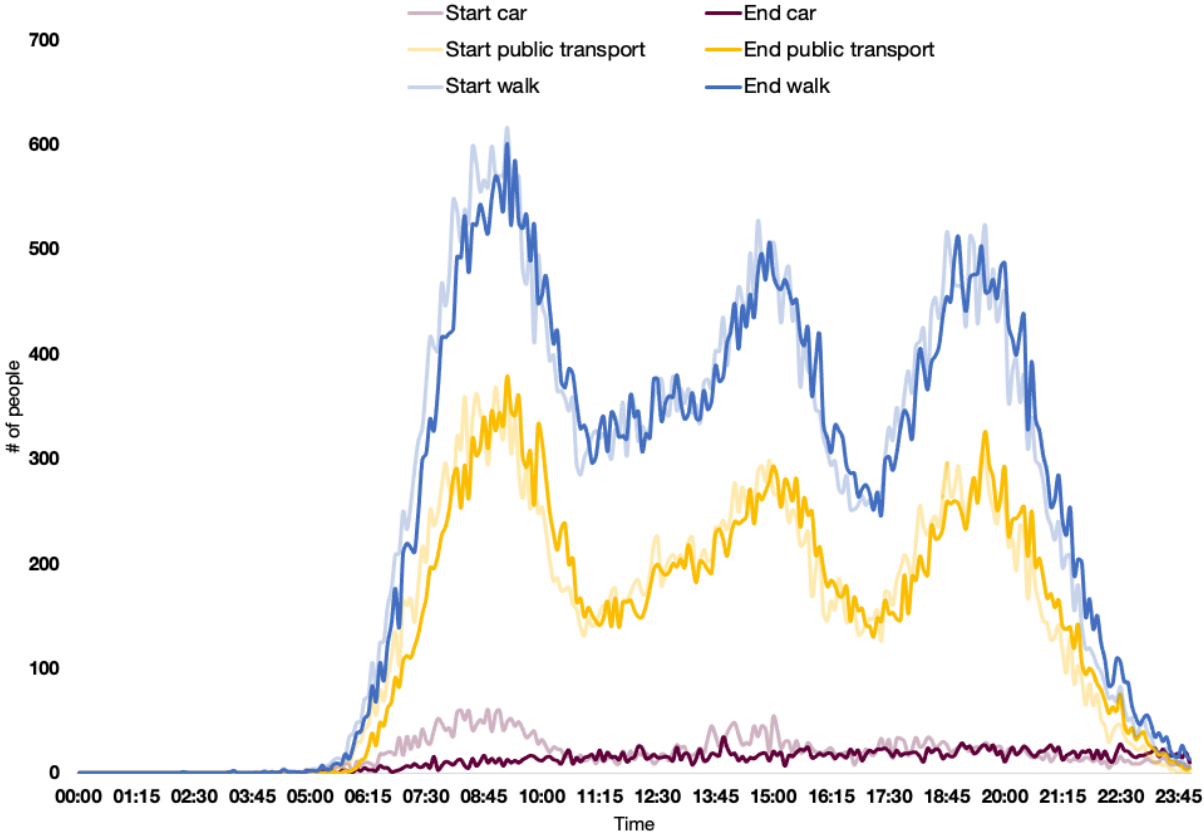


Figure 51: Start and end times by mode for iteration 400 (0.1% population sample; CC BY 4.0)

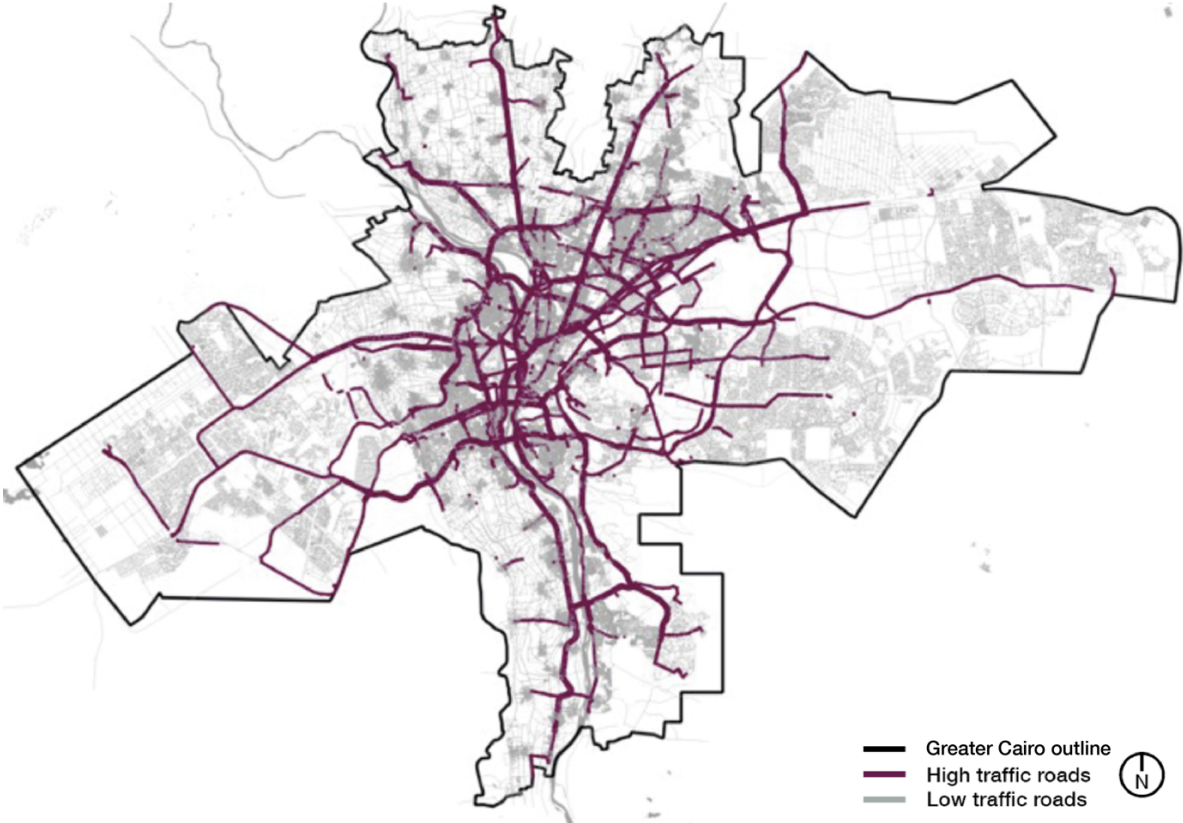


Figure 52: Map of Cairo with simulated traffic counts for 2022 simulation represented by width of red links (Data sources: Infrastr. from OSM, Boundary from TFC, Traffic counts generated by authors via MATSim; CC BY 4.0)

5.2.3.1 Scenario simulations

After the simulation of the present urban mobility system, the four developed, localised scenarios are simulated. For each of the scenarios, the planned future rail-based mass transit is integrated, including metro extensions, new lines, a mono-rail connecting the western and eastern new towns, and a high-speed electric train connecting the same two areas via the lower half of a circle passing central Cairo in the South (Figure 56). They are assumed to be completed as planned by latest 2030. Several of them aim to connect the new Capital City east of New Cairo which is currently in construction but due to few residents so far and lack of data outside of the geographical scope of this study. Future simulations must pay attention to either further developments and their integration in simulations, or alternatively consider the risk that some mass-transit projects might slow down or be modified if the new Capital City is not developing as currently foreseen.

Aside from the future transport supply described above that is integrated across the four scenarios, the synthetic population is adapted using two uncertainties. One is the distribution of where the population will live by 2030. We distinguish between sprawl and densification, translated into modified average density for each of the 74 qism (urban sub-division). Regardless of their spatial distribution, the population is assumed to grow from 22.9M people today to 25.5M in 2030. Equation 16 is used to adapt the densities per area for the two densification scenarios. Equation 17 adapts the densities for the two sprawl scenarios. Annex AN.7.3 shows the detailed numbers for each area and scenario.

$$D_{2030a,i} = D_{2022,i} + \left((\max(D_{2022,l}) - D_{2022,i}) \times 0.00932 \right) \quad (6)$$

$$D_{2030b,i} = D_{2022,i} + (20000 - D_{2022,i}) \times 0.07695 \quad (7)$$

where:

- $D_{2022,i}$: 2022 population density for area i
- $D_{2030a,i}$: 2030 population density for area i in densification scenario
- $D_{2030b,i}$: 2030 population density for area i in sprawl scenario
- $\max(D_{2022,l})$: Maximum density of all areas in 2022

Equation 6 takes the difference between the maximum density in 2022 and the 2022 density for the respective qism and multiplies it by a calculated factor to reach an overall population of 25.5M. This results in a densification primarily in areas with currently lower densities. Equation 7 maintains this logic but replaces the maximum density by 20,000 people. The latter number is chosen as current projects and planning policy aim for lower densities and 20,000 could be seen as potential average target value. The numerical result of these transformation can be found in detail in AN.8 and as well as being visualised in Figure 53 and Figure 54. The former plots the distance to the Cairo's geographical centre⁴⁸ and shows in red the 2022 densities, in

⁴⁸ Identified by calculating the geographical centre of the centroids of each of the 74 qism, weighted by their population, meaning higher populated areas shift the centre towards them. The resulting centre is located between Ramsis Square (ميدان رمسيس) and Al-Fath Mosque (مسجد الفتح).

yellow the 2030 densities for the densification scenarios, and in grey the ones for the sprawl scenarios. Exponential trendlines have been added despite limited statistical fit to highlight the shifting distribution of densities. We can make three observations:

1. The higher the initial density, the larger the impact, mostly for the sprawl scenarios.
2. The densification scenarios add primarily population in the less populated central and medium-distance areas while the sprawl scenarios add more also in the farther areas and reduce mostly in the central areas (in line with current inner Cairo resettlement and transformation projects).
3. While for the changes for the densification scenarios are mostly homogenously proportional to the initial density, the sprawl scenarios result in changes dependent on the difference between the 2022 density and the 'target' density of 20,000.

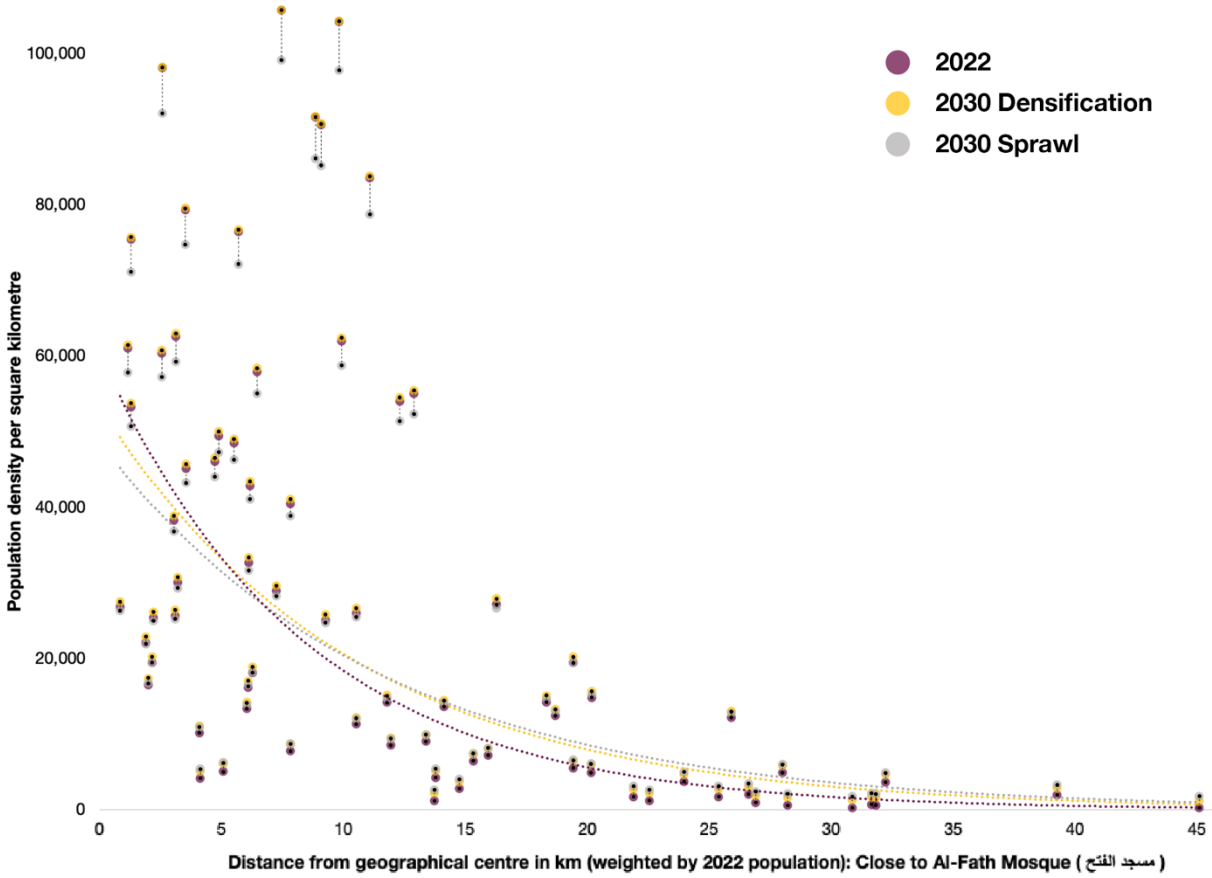


Figure 53: Population density in 2020 and dense or sprawled 2030 scenarios plotted with distance to geographically weighted centre on x-axis and population density on y-axis (exponential trendlines for visual support of transformation per scenario; CC BY 4.0)

Figure 54 shows the spatial distribution via three maps, with darker red signifying higher densities. The upper left map shows the current situation and the upper right the similar densification scenario with the major change being the increase of the overall population and little densification potential in the already very dense central areas. The bottom map shows the distribution for the sprawl scenarios, making the increase in more distant areas visible.

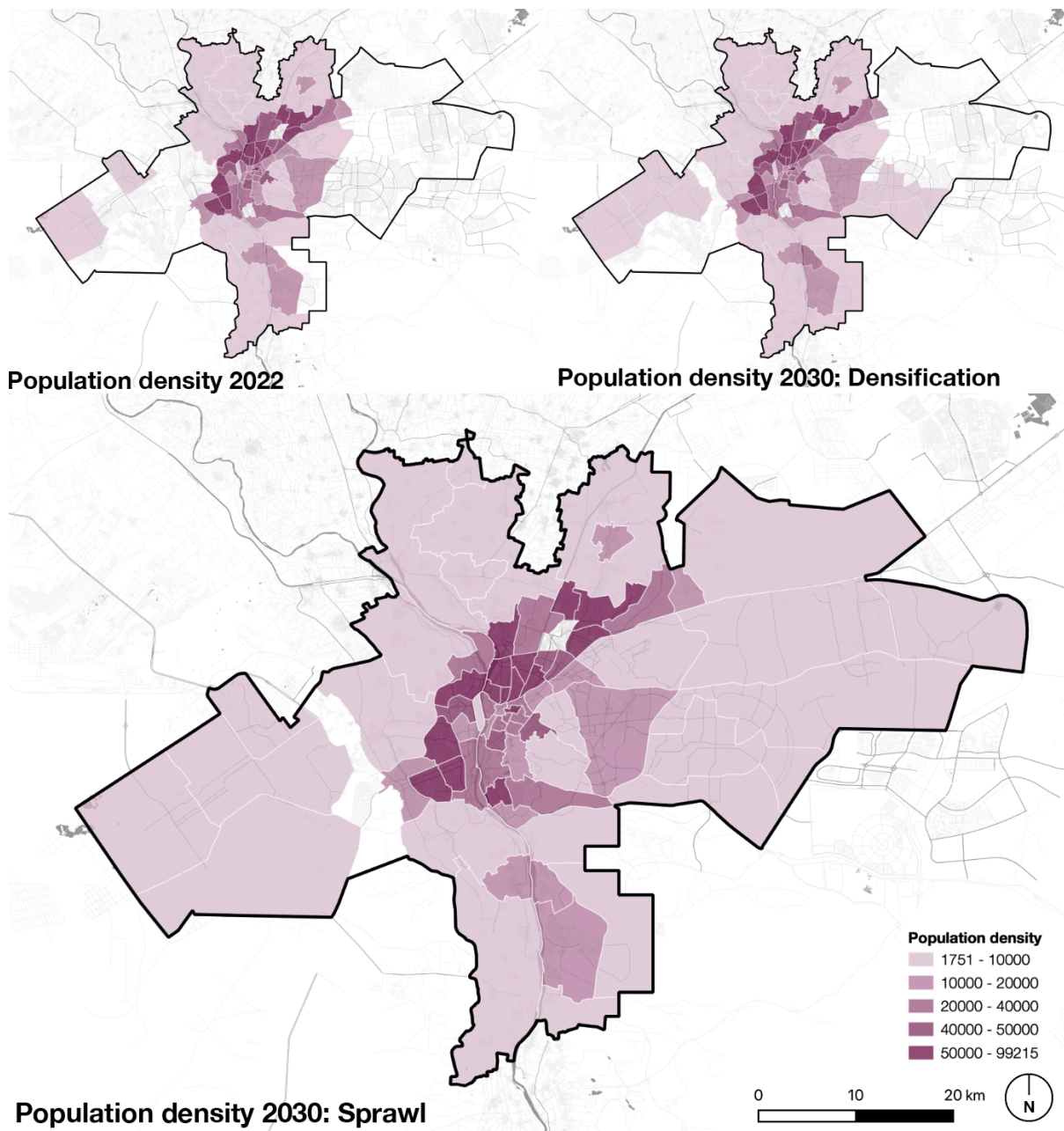


Figure 54: Cairo's population density distributions for 2022 and 2030 scenarios at *qism* level (قسم) in people per sqkm (Data sources: Streets from OSM, Outline from TFC, Present population adapted from CAPMAS 2017 densities, future population generated by authors; CC BY 4.0)

The second adapted parameter for the future scenarios is the *rate of car ownership*, identified as another critical uncertainty and proxy value for middle class development. To adapt this, not only the number of people per area must be changed but also the distribution within. We replicate here the approach developed in Paris with the objective to create four variations of synthetic populations. The available data in Cairo is less detailed.

The clustering is therefore done with the factors remaining in the synthetic population for the base simulation: gender (binary), currently in education (binary), primary activity (categorical), vehicle ownership (binary), number of trips (numerical), activity (categorical), distance to activity (numerical), start time of first activity (numerical). The numerical variables are normalised, and the others are coded as unordered categorical values. To identify a suitable number of clusters, the clustering of a random 0.1% sample of the overall population (22.9 M) is conducted for two to 30

clusters for all even intermediate steps. An ‘elbow’ can be identified at 10 clusters which is chosen for the subsequent steps (see Annex AN.7.3 for graph).

The clustering of ten clusters has been repeated with a 5% sample to generate more reliable centre values (Table 28) which are used to predict the clusters of the total population (distribution in the second column of Table 28). The proto-personas resulting from the clusters could be used to develop full personas enriched with qualitative information. As the focus of the following is on the synthetic populations, these are not further discussed here.

Table 28: Central values for ten Cairo clusters

PP	# M	Gender	Edu.	Prim. act	Car	# trips	Purpose	Dist.	Start time
1	1.9	male	0	work	0	4	personal	11	11:41
2	2.8	female	1	primary	0	3	primary	3	13:14
3	1.8	female	0	work	1	3	work	8	12:53
4	2.2	male	1	Sec.	0	3	secondary	16	12:22
5	1.7	male	0	work	0	5	work	12	18:30
6	1.3	male	0	work	1	2	personal	11	11:28
7	2.8	male	1	primary	0	3	personal	5	09:42
8	1.5	male	0	work	1	4	work	13	09:37
9	2.8	female	0	work	0	2	personal	8	12:55
10	4.0	male	0	work	0	2	work	11	10:06

Total 22.9* **Different than sum due to rounding.*

Even if the estimated 2022 population is 22.9M people, we conduct the following steps with a population of 15.3M which is the part of the population with at least one trip per day and thus relevant for the mobility simulation.⁴⁹ From this population, 20% have access to a car in the household. This matches an estimate of 19% car ownership in the Cairo Governate (Samaha and Mostofi, 2020). For two of the scenarios, we assume a *stable car ownership rate*. This means 20%. However, the population increases from 22.9 M to 25.5 M, resulting in a significantly higher number of cars.

For the two remaining scenarios with an anticipated motorisation percentage increase, we assume a continuing growth of cars per household. We use the growth rates between 2010 and 2021 as basis which hover between -8% (2019-2020) and +12.9% (2014-2015)⁵⁰. Excluding the pandemic year decrease in 2020 (Annex AN.7.3), we have an average annual growth rate of about 6.9%. Normalising by an annual population growth of +2%⁵¹ in the same period, this results in an average increase of 4.9% more cars per capita per year. Assuming this to apply homogeneously to the current rate of 20% car access in the synthetic population, a car access rate of 29.3% is assumed for the two car-centric scenarios.

⁴⁹ Based on travel interviews conducted by TFC asking respondents about the number of trips on the previous day. As it has been an intercept survey, it might be that stay-at-home individuals are still underrepresented but there is no other data on which we could make an informed estimation.

⁵⁰ Data source: <https://www.ceicdata.com/en/egypt/number-of-registered-vehicles-annual/no-of-registered-vehicles-private-cars> [accessed 14 July 2023]

⁵¹ World Bank data (<https://data.worldbank.org/indicator/SP.POP.GROW>) [accessed 14 July 2023]

Based on a homogenous population growth for each scenario, the two different spatial population distributions sprawl and densification, and the two car ownership evolutions, we can adapt the original synthetic population. This is done in three steps.⁵²

1. The 15.3M moving people in the current synthetic population are assigned to one of the qism areas based on their home location.
2. For the two scenarios with stable car ownership, the populations are scaled linearly for each qism according to the established changes of the populations.
3. For the remaining two scenarios, the population must be first adapted to match the target car access rates. As we have only one variable, no iterative proportional fitting as in the case of Paris is needed. Instead, a scaling rate for the proto-personas with and without vehicles can be calculated for each area to reach the target car access while reaching a population of 25.5M (and the equivalent of about 17.2M people moving).

This results in one synthetic population for each of the four scenarios (Table 29).

Table 29: Overview of trend and uncertainties across scenarios

	Present situation	Scenario 1 Auto-sprawl	Scenario 2 Disconnection	Scenario 3 Gridlock	Scenario 4 Urban revival
Trend: Moving population	15.3M	17.2M	17.2M	17.2M	17.2M
Trend: Public transport (PT)	Current PT	Future PT	Future PT	Future PT	Future PT
Uncertainty: Spatial development	None	Sprawl	Sprawl	Densification	Densification
Uncertainty: Car ownership	None	+4.9%/year	Stable	+4.9%/year	Stable

The two scenarios with constant motorisation rate (scenario 2 ‘Disconnection’ and scenario 4 ‘Urban revival’), are scaled to about 17.2 M people who take at least one trip on an average day. Their spatial distribution is more sprawling in scenario 2 and more central in scenario 4, keeping the same proto-persona distribution as shown in Table 28. For scenario 1 ‘Auto-sprawl’ and scenario 3 ‘Gridlock’, the personas were reweighted to match the higher motorisation rate while reweighting geographically according to sprawl or densification parameters.

Table 30 shows the proto-persona distribution for scenarios 1 and 3, as well as the change of the proportional percentage of each proto-persona within the overall population. With this, the base components for the future scenario simulation are prepared.

Table 30: Proto-persona distribution for scenarios 1 and 3, showing the evolution of the percentage of each persona as part of the overall population

Scenarios 1 and 3	
Persona 01	712k (-4%)
Persona 02	1,443k (-4%)

⁵² The replicable and detailed process can be found in the notebook ‘06b_cluster-reweighting’ in the git repository referenced at the start of this section.

Persona 03	1,179k (-1%)
Persona 04	1,298k (-2%)
Persona 05	4k (-7%)
Persona 06	1,943k (+6%)
Persona 07	2,524k (+2%)
Persona 08	1,445k (+2%)
Persona 09	2,700k (+3%)
Persona 10	3,941k (+5%)
Total	17,189k

5.2.3.2 Selection and descriptions of interventions

In this section, we select and describe possible future solutions in the urban mobility system. To replicate and extend the application case in Paris, we chose to compare multiple potential interventions individually and in combination across the 2030 scenarios.

Potential interventions in the urban mobility context can be anything including technological, infrastructure, social engineering, urban planning, or public policy solutions.⁵³ Together with the local partners, we chose three interventions that fulfil some key requirements: First, the interventions must be possible to be integrated in the simulation framework. Second, they shall origin from different fields to highlight methodological potentials. Lastly, they shall consider current discussions and considerations in Cairo, among others resulting from the expert interviews and workshop, and have an actual potential to improve the people-centredness and sustainability of urban mobility in Cairo. *The three solutions chosen are a Bus Rapid Transit (BRT) system on the principal ring road, an improved walkability around stations, and facilitated intermodality.* The following sections briefly introduce each solution and describe how they are modelled in the agent-based simulations.

The first potential solution is a BRT system. Since first developed in Curitiba, Brazil, in 1974, it has been replicated in various cities globally. The main advantages are that it can carry a higher capacity due to optimised boarding and dedicated lanes, often comes with larger busses and higher average speeds, while being much cheaper and more flexible than rail-based mass transit options. Figure 55 shows a conceptual diagram highlighting the core elements, here for the multi-lane ring road of Cairo. First, there is a dual-direction dedicated lane, usually physically separated to ensure that busses can pass traffic and are not blocked. Second, stations resemble rather tram stops than tradition bus stops. They are often in the middle of the road, accessible via a dedicated pedestrian infrastructure and with a ticket purchase and fare collection system at the station instead of inside the bus. Usually, the platforms are raised, and multiple doors permit rapid disembarking and boarding.

⁵³ See Annex AN.9 for an excerpt of an urban mobility solution database.

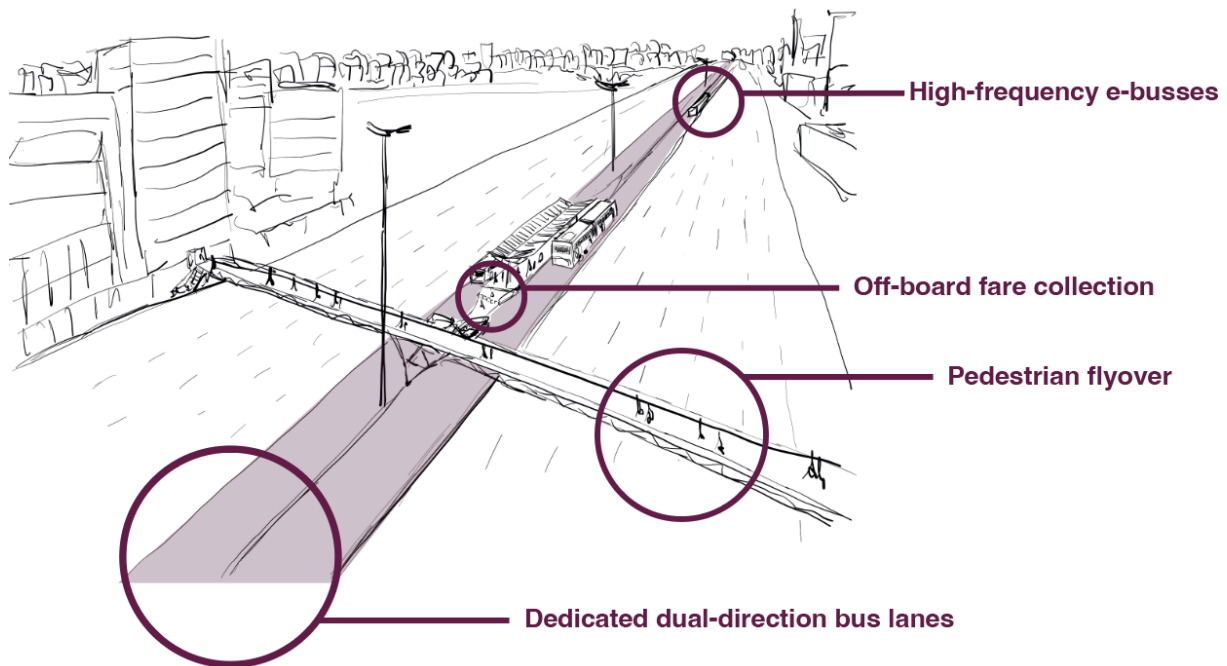


Figure 55: Bus rapid transit on Cairo ring road concept diagram (CC BY 4.0)

Figure 56 shows a BRT route which is currently considered in Cairo. It forms a circle of a bit under 100 km with 46 stops on the ring road surrounding most of central Cairo and passing New Cairo in the east. The service operates in both directions. Currently, regular announcements and public discussions are ongoing. In May 2023, Egyptian Transport Minister, Kamel al-Wazir, was in Qatar to discuss with Qatari institutions on potential operation of the Cairo BRT system⁵⁴. The Institute for Transportation and Development Policy (ITDP) created a prefeasibility assessment for Greater Cairo in June 2015, emphasising various key elements, such as dedicated lanes, validation of tickets before boarding the bus (off-board fare collection) and elevated stations to facilitate short stops, and traffic management that priorities BRT vehicles at intersections (ITDP, 2015). While plans seem to be relatively far developed, we are not aware of any ongoing constructions of stations or lanes. BRT's current political interest and the high potential to supplement existing and planned mass transit transport supply make it an interesting solution to test generally in the simulation and across the set of scenarios.

⁵⁴ Egypt Independent, 16 May 2023, Egypt, Qatar discuss operating Cairo's BRT system (<https://egyptindependent.com/egypt-qatar-discuss-operating-cairos-brt-system/>)

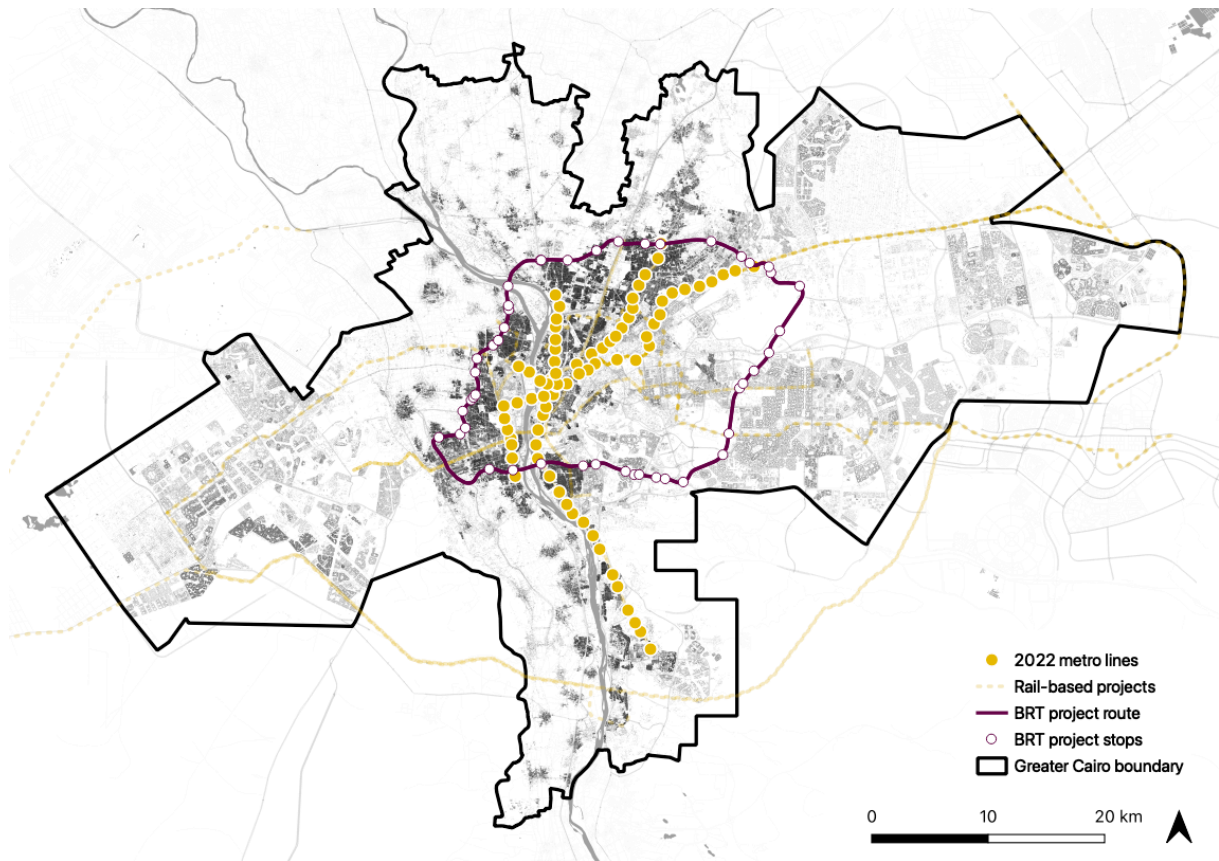


Figure 56: Map of existing metro network (yellow dots), planned rail-based mass transit projects (light yellow), Bus Rapid Transit (BRT) project on ring road route (red line) and stops (white-blue dots) within Greater Cairo (bold black outline) (Data sources: Infrastr. from OSM; Public transport and metropolitan area outline from TFC; CC BY 4.0)

The second solution origins from the discipline of urban planning and design. Mass transit success is impacted largely by the catchment area of stations as it defines how many people can reach a station. In practice, this is defined at three levels (Figure 57). First, the urban form defines the reachability. As smaller the blocks are, as more walkable (cf. Jacobs, 1961). Large infrastructures such as highways or railways with limited possibilities to cross can have an additional impact. Second, the quality of the walking infrastructure impacts the likelihood for some or all user groups. Third, a variety of other parameters, such as shading, perceived security, passing interesting/high-quality spaces, or the co-location of other waypoints like grocery

shops or a postal office (cf. Transit-oriented Development) can impact the likelihood of people to walk.

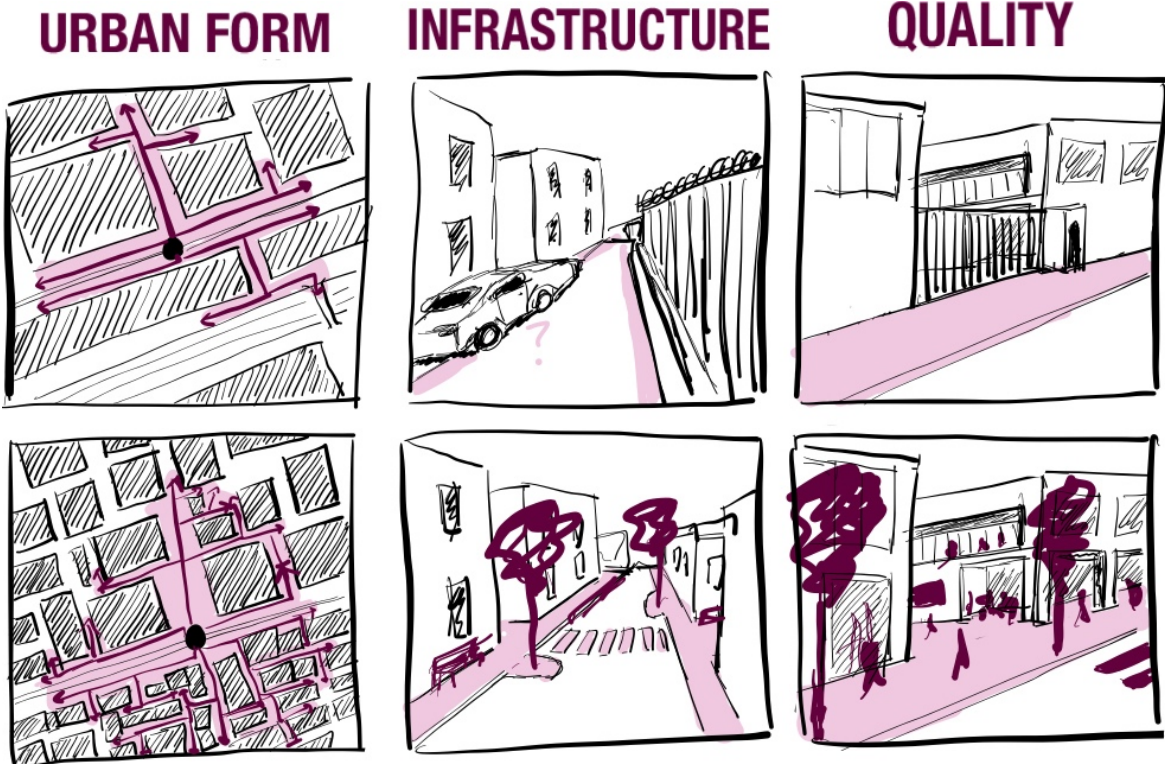


Figure 57: Three aspects impacting walkability (left: urban form, centre: infrastructure availability and quality, right: quality of public space; CC BY 4.0)

The objective is not to specify which type of intervention could be implemented across all Greater Cairo. Instead, the objective is to measure how a set of place-specific measures that increase the walkability everywhere could have an impact on the overall mobility system. For this, we turn to the choice model of MATSim. Every agent attempts to maximise her individual utility (Horni et al., 2016). The utility is a function of primarily time and cost within the constraints of available options (e.g., car availability) (Hörl, 2023; Balać et al., 2023). In more detail, different values are integrated, such as travel time, parking pressure, headway, in-vehicle time, waiting time, per km or standardised public transport costs (Hörl, 2023). With this basis, a utility is calculated for each agent, calibrated based on, e.g., Household Travel Surveys. In the first simulation iteration, everyone uses the car. This leads to significant congestion and negative scores for many, mostly those who do not have access to a car. Afterwards, maximum 5% of the agents can choose a different mode/route in the next iteration, simulating a dynamic iterative learning mechanism. For this intervention – as well as the next one – we make use of the utility function components to estimate the impact of here improved walkability.

Figure 58 visualises this concept. On the y-axis is the score resulting from possible walking distances to a station (x-axis). In this model, it is not possible to have a positive score resulting from walking. Instead, there is a linear relationship between the distance of the station and the score. The farther the distance, the lower the score. In practice this means that depending on the availability of other options, at a certain distance the negative impact on the utility of walking to the station is too high to still consider the public transport option. This cut-off point is in planning practice often set at 400-450 minutes – the distance it takes on average 5 minutes to walk – and in reality, often higher depending on transport supply, alternatives, climate, or social

practices. For the second intervention, we move this curve upwards to model the willingness to walk a bit further. We assume an improvement of 15% compared to the current situation for testing purposes in this use case. It could be envisaged to conduct a stated preference survey to quantify the monetary value of an improvement of certain type to detail this adaptation further.

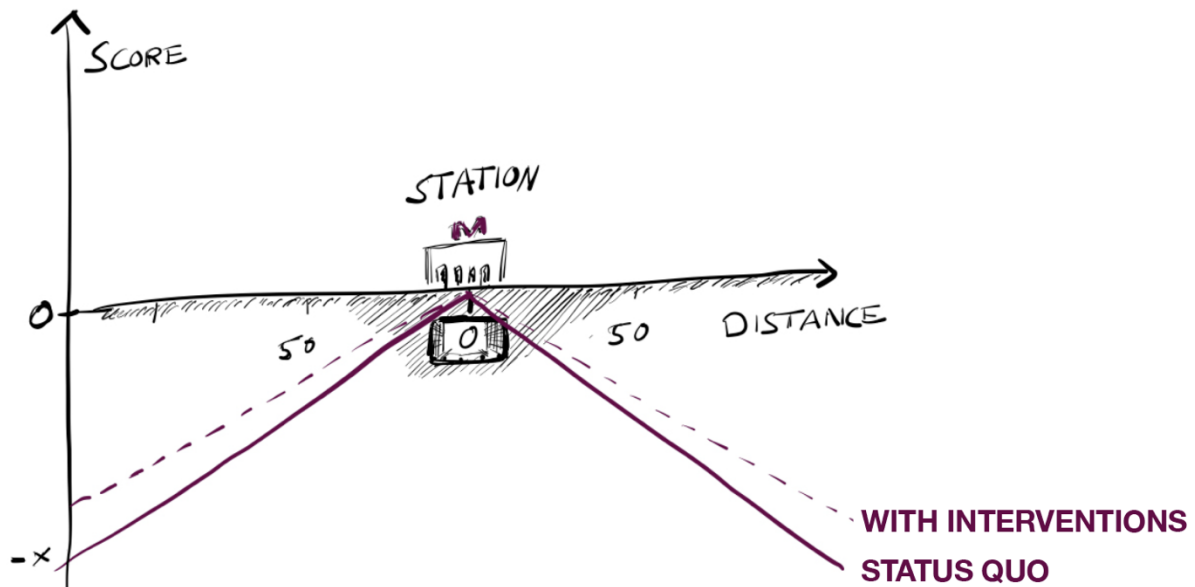


Figure 58: Graph showing increasing score for walking (y-axis) if interventions are introduced (dotted red line) compared to status quo (continuous red line). Meaning, the score (utility) is reduced less for the same distance, thus, leading to longer walking distances with equal score (CC BY 4.0)

The third and final intervention relates to smart and sustainable cities, Mobility-as-a-Service (MaaS) and transport data management. Inter- and multimodal transport is often mentioned as important component of sustainable urban mobility systems (Oostendorp and Gebhardt, 2018). Intermodal transport refers to ‘transportation by more than one form of carrier during a single journey’ (Goetz, 2009) while multimodality is defined as the ‘use of at least two modes of transportation—bicycle, car, or public transportation—in 1 week’ (Nobis, 2010).

As the simulations are focusing on one day, we focus here on *intermodality*. Public transport users are more likely to use one bus or metro even if it takes slightly longer than a combination of multiple modes (cf. Oostendorp and Gebhardt, 2018, for more detailed elaborations impacts of intermodality). This can result from the disturbance of on-board activities, risks of delays or prolonged waiting times, or comfort reasons. For this reason, intermodal exchanges (e.g., bus to metro) are currently integrated in the simulation’s utility function as a penalty term. This has particular relevance in Cairo where ‘focus group findings also indicate that passengers actively avoid transfers [...] which is likely to reflect uncomfortable, disorganized [sic] and unsafe interchange environments as well as service unreliability which together cause transfer stress’ (TFC, 2021).

Different types of information can improve the willingness to transfer between modes and use intermodal trips and thus strengthen an important component of sustainable urban mobility transitions (Figure 59). A first example is the *improvement of the physical transfer point*. This can include more developed stations and lighting, shading, camera surveillance or other protective measures. Secondly, the transformation and adapted management of the *space around stations* can lead to

improved intermodality, e.g., by having a dedicated area outside of a metro station where buses can be accessed directly and safely. Third, the access to *up-to-date information* is crucial. If somebody knows that the connecting mode will arrive in a few minutes and can rely on it, she will be more likely to consider it as an option.

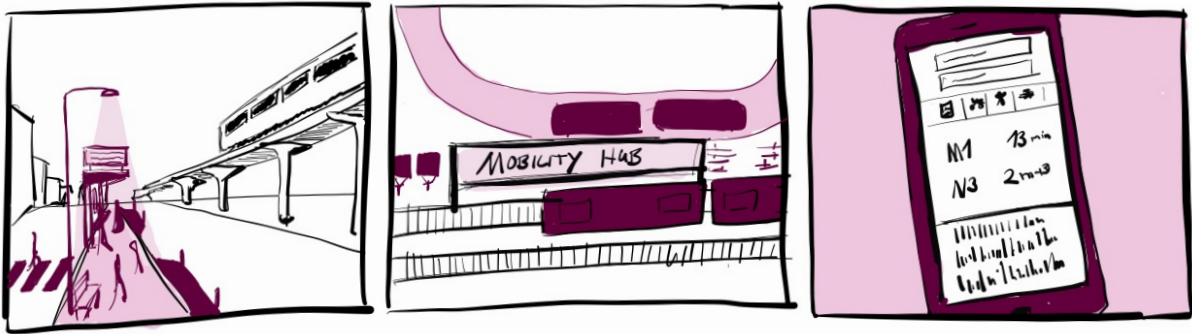


Figure 59: Three possible enables for intermodality (left: safer stations, centre: stations as mobility hubs with improved space management, right: real-time information; CC BY 4.0)

This requires a combination of transport data management, sharing between providers, digitalisation in general across modes, as well as different information access points, such via smartphone apps, existing mobility providers, and information panels. Again, we do not intend to suggest a single solution for every situation but instead aim to quantify the potential impact an improvement of intermodality could have at a systemic level. For this, similar as before, we assume an improvement by 15% of the value use in the baseline simulation, meaning a *reduction of the penalty score for intermodal transfers*. Equation 8 shows the standard travel disutility used in MATSim with the changing component highlighted (Nagel et al., 2016).

$$S_{trav,q} = C_{mode(q)} + \beta_{trav,mode(q)} + t_{trav,q} + \beta_m \times \Delta m_q + (\beta_{d,mode(q)} + \beta_m + \gamma_{d,mode(q)}) \times d_{trav,q} + \beta_{transfer} \times x_{transfer,q} \quad (8)$$

where:

- $C_{mode(q)}$ is a mode-specific constant
- $\beta_{trav,mode(q)}$ is the direct marginal utility of time spent traveling by mode
- $t_{trav,q}$ is the travel time between activity locations q and $q + 1$
- β_m is the marginal utility of money (normally positive)
- Δm_q is the change in monetary budget caused by fares
- $\beta_{d,mode(q)}$ is the marginal utility of distance (normally negative or zero)
- $\gamma_{d,mode(q)}$ is the mode-specific monetary distance rate (normally negative or zero)
- $d_{trav,q}$ is the distance travelled between activity locations q and $q + 1$
- **$\beta_{transfer}$ are public transport transfer penalties (normally negative)**
- $x_{transfer,q}$ is a 0/1 variable signalling whether a transfer occurred between previous and current leg

In the base choice model⁵⁵ used for this study, a penalty of €0.39 is attributed to each minute walking to, from, or in between public transport stations. A cost equivalent to €0.83⁵⁶ is attributed to a transfer between two public transport modes. With the respective reduction of 0.15%, this results in about €0.33 for intermodal transfers and

⁵⁵ Calibrated on detailed Household Travel Surveys of the Île-de-France region.

⁵⁶ Based on an estimated value of €1 for a score improvement of 0.206 points. €0.83 equals about 28 EGP with the exchange rates of 22 July 2023.

€0.71 for walking. Additional to the local choice model calibration, a stated preference survey in Cairo could permit to provide more solid input values for this part.

5.2.3.3 Impacts of interventions across scenarios

In the last step, the four developed scenarios for 2030 with their respective synthetic populations and the three considered solutions can be modelled. A potential of agent-based simulations compared to other models is the consideration of systemic impacts of the choices of other agents and the interplay of different services. Hence, we not only simulate the scenarios with each intervention separately but also with different possible combinations (Table 31). This results in one base simulation of the present (s0), four simulations of the contextual scenarios for 2030 without interventions (s-a), 12 simulations for each intervention individual across the scenarios (s-a, s-f, s-h), 12 simulations combining each time two solutions across scenarios (s-c, s-e, s-g), and four simulations where the combination of all three intervention is tested together (s-d). This results in a set of 33 simulations. The goal in the result discussion is not to analyse all resulting data but instead highlight some potentials.

Table 31: Overview of simulated scenarios, integrating base simulations and variations of combined interventions

Scenario		Mobility services (BRT: Bus Rapid Transit W: Walkability I: Intermodality)							
		Base	BRT	BRT/W	BRT/W/I	BRT/I	W	W/I	I
2022		S0							
2030	S1: Auto-sprawl	S1a	S1b	S1c	S1d	S1e	S1f	S1g	S1h
	S2: Dis-connect	S2a	S2b	S2c	S2d	S2e	S2f	S2g	S2h
	S3: Grid-lock	S3a	S3b	S3c	S3d	S3e	S3f	S3g	S3h
	S4: Urban revival	S4a	S4b	S4c	S4d	S4e	S4f	S4g	S4h

To focus on the comparative character, we provide normalised per capita values for five representative indicators, each time for the last simulated iteration (n=100). The score refers to the calculated utility. CO2e is calculated by the number of car vehicles multiplied 150g CO2e/pkm. The time is the total amount of time spent per day and person. The walking indicator results from the percentage of walked trips for those shorter than 1 km. The public transport indicator shows the modal share for trips longer than 1 km. CO2e and time are both reversed to have homogenously more positive values as higher the value is. Figure 60 (left) shows the comparison of the 2022 situation (transparent grey) with the four scenarios.

Scenario 1 ‘Auto-sprawl’ has clearly the lowest values, followed by Scenario 2 ‘Gridlock’. Scenario 3 ‘Disconnection’ has the highest score in walking, most likely resulting from the fact that low density and few cars result in the necessity for most people to walk regardless of trip length. Scenario 4 ‘Urban revival’ performs similar to 2022 as the only 2030 scenario and clearly outperforms the other future scenarios.

On the right side of the same figure, for each of the future scenarios, the base option (future transport supply and population) and the option d (with BRT, walking,

intermodality) are compared. Two findings are noteworthy. First, the worse the scores are, the higher the impact of the interventions. The two scenarios with a car ownership rate increase (S1, S3) are benefitting most. On the other hand, the Gridlock scenario achieves an identical public transport rate for trips over 1 km, highlighting the potential to shift people to public transport even if more cars are there as long as the population density permits the access to public transport.

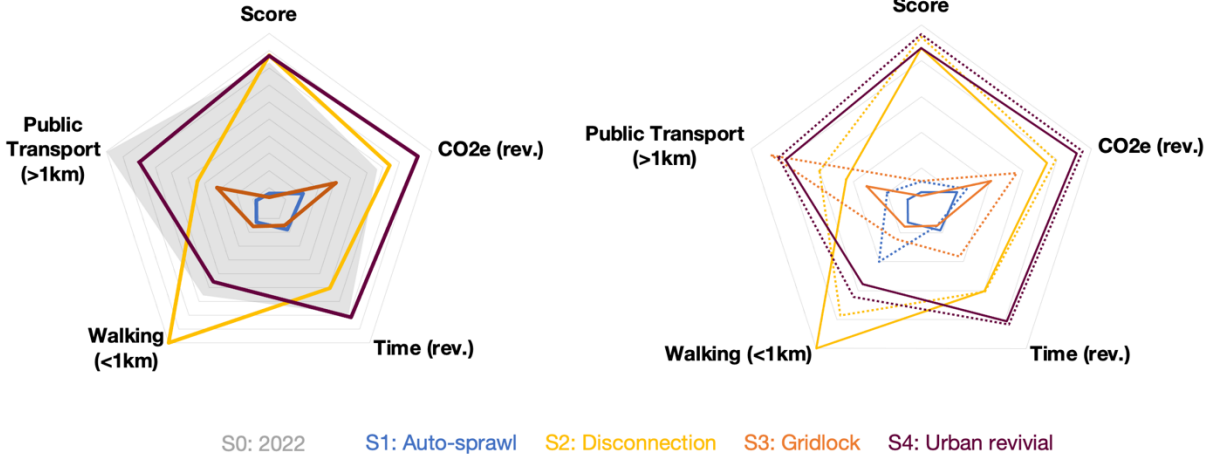


Figure 60: Left: Comparison of 2022 scenario and four 2030 via five indicators. Right: Comparison between base scenario (continuous line) and option d with BRT+walking+intermodality for each of the scenarios (CC BY 4.0)

If we take each of the five indicators with an equal weight, the ‘Auto-sprawl’ scenario performs the worst and the ‘Urban revival’ as the best. To analyse the impact of the different interventions, we zoom on those two in Figure 61. On the left, we see the ‘Auto-sprawl’ scenario. The base option (black dotted line) is relatively homogenously underperforming across the five indicators. The other scenario options (grey lines) are performing slightly better across all categories except the time spent. However, only the option combining BRT, improved walking to stations, and intermodality performs significantly better in general. On the other hand, the impacts are less clear for the scenario ‘Urban revival’ where the option without changes does not perform worse than the base scenario. This could be interpreted by a lower sensitivity to the walkability and intermodality indicators as a more densified urban form permits to walk to stations in any case or alternative reach more places close by. The BRT system on the ring road is less relevant as more people live centrally and have access to other modes of transport. However, it is important to understand these values just as general indication. A more detailed interpretation of the minor differences would require simulations with higher sample sizes and a locally calibrated choice model, as well as a sensitivity analysis for the parameters of the options.

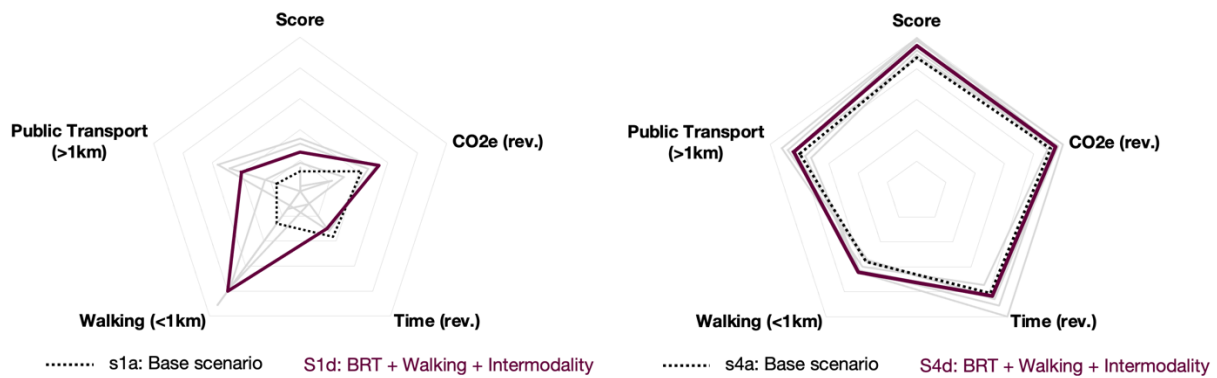
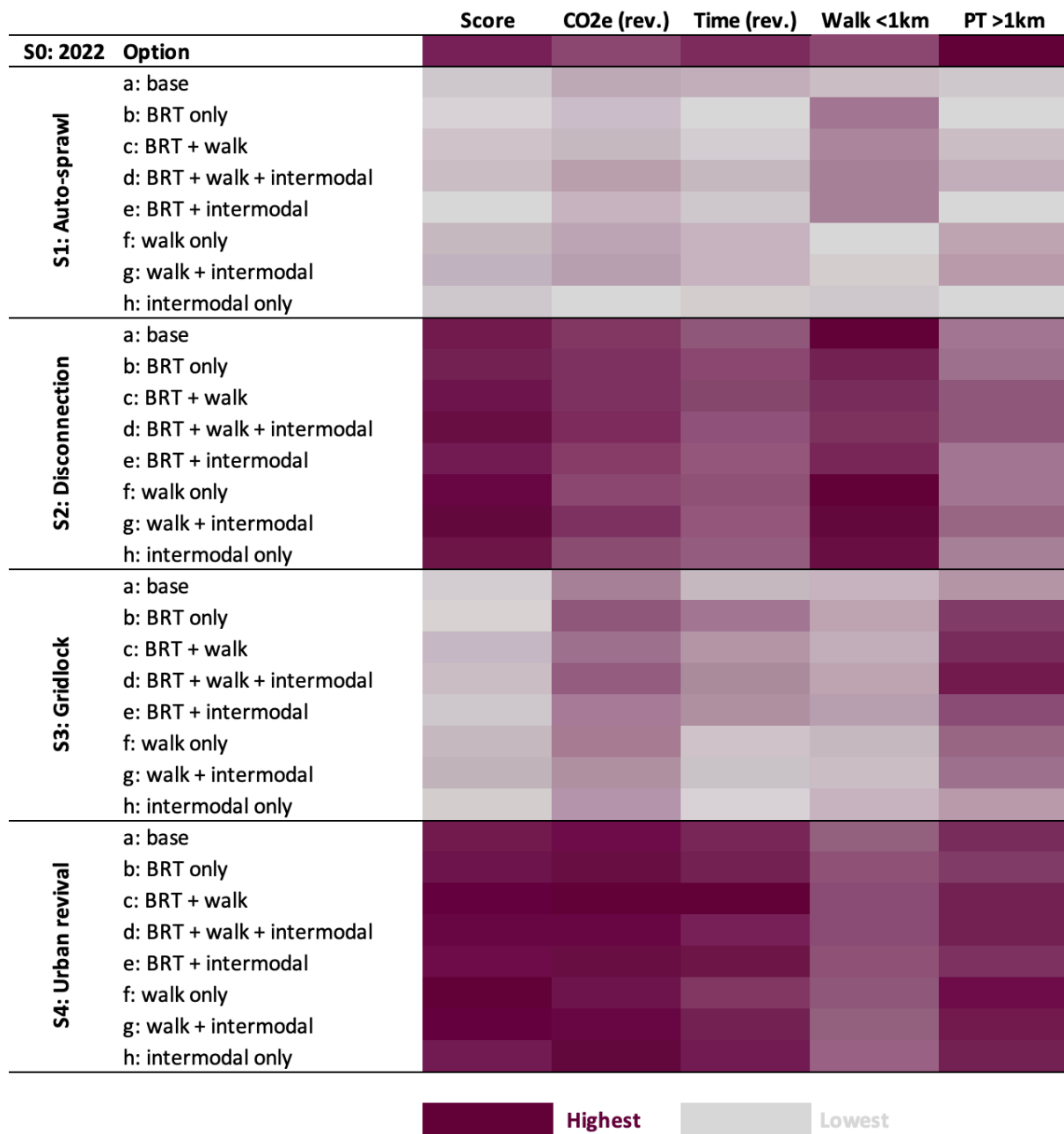


Figure 61: Comparison between base scenario (black dotted line), all three interventions (red line), and other partial options (grey lines) for 'Auto-sprawl' (left) and 'Urban revival' (right) (CC BY 4.0)

Other analyses, such as those conducted for Paris-Saclay, or more geographically or user-group focused ones, could be envisaged. However, due to the mentioned needed methodological improvements for the agent-based simulation, the decision was taken to stay on a higher-level and systemic analysis. To complete the comparison via the five indicators, Table 32 shows a heatmap of all scenario options. It confirms the previous assessment of scenarios 2 and 4 (with stable car ownership rates), outperforming the other two. Comparing between the pairs with and without changes of the car ownership, both times the densification scenario outperforms the sprawl one.

Table 32: Heatmap of values for all scenario options and the five indicators from low/negative (light grey) to high/positive (dark red)



5.2.4 Discussion of Cairo case and conclusion

This sub-chapter presented the second application case and the replication of several elements of the proposed methodology. Taking a general perspective, a few elements must be noted. The case study of Cairo was chosen to test the overall methodological framework as well as components thereof in a very different context with limited time, resources, and local expertise. This refers particularly to scenario-based approaches, their co-creative localisation and transformation through trends, uncertainties, and archetypes, as well as the application of the urban mobility system model with a special attention to future urbanites and rendering them tangible via data-driven personas and synthetic populations.

We can conclude that this has been largely successful and simultaneously confirmed various pre-existing assumptions and elements as well as further refining the applied method. The rich environment during the research visit – as well as continued

collaboration since – has enabled to gain in-depth insights in the local system dynamics, as well as exchange with local experts with various profiles, including mobility and transport planners, urban planners, policymakers, and economists. The scenario-based and transdisciplinary approach has received positive reactions throughout and permitted to jointly elaborate while taking different perspectives on the complex challenge of transforming urban mobility systems.

Additional to the elements of replication and method testing, an interest and high potential of building an agent-based simulation for Greater Cairo has been identified early during the research visit. What started as an idea and objective to create a feasibility study, has resulted in a close collaboration with the data team of TFC and resulting in a set of present and future scenario simulations. While many potentials for improvement remain – which will be discussed in a bit – the simulations, their reliance on mostly open data, their replicability, as well as the components such as synthetic populations, an extensive database on the building stock, a database on activity locations, and spatial growth scenarios all represent building blocks that can – and will – find application in other projects and hopefully can be also reused by others.

While the results are not conclusive at this stage, they point in some directions that can inform a few policy recommendations. First, and on a larger level, Cairo – at least as much as most other metropolitan areas – is highly complex and full of uncertainties. The consideration thereof in policymaking and project planning bears further potential in the context of Cairo. Similarly, *the use of already available data permits more detailed and systemic understandings of the intricacies of Cairo.*

Regarding the scenarios, we can highlight the significant and negative impacts of the scenarios with increasing car ownership rates. Current development patterns of continuously adding lanes and road infrastructure will not resolve the already today gridlock-like situation. Instead, recent investments in public transport of various types point in a direction of more effective, sustainable, and equal mobility supply of tomorrow. *The three tested interventions all show potential positive impacts.* While we do not claim to provide detailed number that would permit, for example, a cost-effectiveness analysis, we hope to have showed that different interventions can have significant, systemic and positive impacts. Individually and even more so if applied jointly. While some interventions require significant infrastructure investments, some others, such as improved data availability and station management, might have significant impacts as well for much less expenditures. Lastly, while all tested interventions, as well as the planned future transport supply seem to improve the situation, *the strongest impact origins from the spatial layout and car ownership.* While the latter can be understood as a complex consequence of needs, resources, and social practices, the former is in the hands of the public sector and the planning bodies. The ongoing sprawl, low density and gated community trends, resulting in increasingly disconnected urban fabric, challenges (among many others) any potential pathway to sustainable urban mobility futures. A policy recommendation is therefore – within limitations of the applied method – the setting of an enabling foundation of the spatial structure, followed up on by a mix of mass transit infrastructure and supporting interventions.

These conclusions are relying on early findings. To increase the reliability of these findings and extend the work, a number of limitations and future work potentials can be mentioned. First, *scenarios should always be adapted to the place-specific needs and regularly updated.* We aimed at providing a method and first set of scenarios but highlight the need to refine and extend them continuously. On the simulation side,

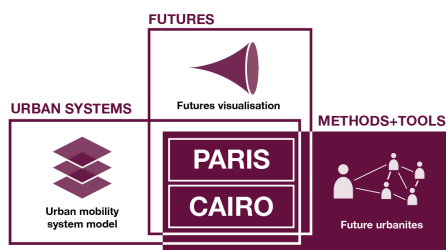
several smaller limitations and potential for future work have been already mentioned throughout this sub-chapter. The most important ones are the further detailing of the synthetic population as well as ongoing calibration to match the observed situation whenever more or higher-detail data becomes available. Further, a set of local specificities that are highly relevant for Cairo's mobility system are both promising as way to improve the model accuracy as well as in some cases interesting research topics. This includes dominant features such as wide-spread one-way streets in many central areas since a couple of years which could be – with the right dataset – easily be integrated and are assumed to improve the simulation quality mostly in central Cairo.

Further, *paratransit and semi-formal on-demand mobility modes that exist in Cairo as well as many other fast urbanising cities could be integrated*. This would allow a higher simulation quality, permit to estimate, for example, the impact of the electrification of tuk-tuks as currently starting across cities in Africa and Asia in relation to its contribution to sustainable and people-centred mobility, as well as providing replicable components for the MATSim framework that could lead to a growing methodological uptake in countries with heterogenous mobility modes. Further, more detailed surveys or other data, such as mobile data, that permit the detailing of the trip chain schedules, would be highly beneficial. Along the same lines, an improved understanding of the local value of time through targeted surveys would permit calibrating the underlying choice model. In Cairo even more than in Paris, *a particular potential lies on understanding and integrating the differences between socio-economic groups as currently even many public transport options remain unaffordable for a significant part of the population* (TFC, 2021).

Lastly, as soon as more accurate and better calibrated simulations are possible, it would be worth it to run sensitivity tests across scenarios and interventions, as well as to scale up the sample sizes at least to 5% for high-level simulations or higher for more local analyses or the integration of dynamic modes such as tuk-tuks or shared on-demand taxis without fixed routes.

5.3 Resulting set of methods and tools

Research question	How can design processes of people-centred mobility solutions for future urban systems be supported?
Methodology	Mixed methods.
Results	Localised urban mobility scenarios, personas, and synthetic populations as intermediary design objects. Two methods to compare and assess potential urban mobility interventions in local context while integrating uncertainty.
Contributions	<ul style="list-style-type: none"> a) Tested and replicable method for localising scenarios. b) Tested and replicable method for integrating scenarios in agent-based simulation. c) Tested and validated support tool for rapid assessment with focus on personas and futures.
Implications	Practical implications of this sub-chapter include the simplified reuse and localisation of scenarios, the use of the created and accessible intermediary design objects, as well as the structured integration of future uncertainties on the people-layer in agent-based simulations.



This chapter started with the question *how to support design processes of future urban mobility solutions in conditions of uncertainty*. We titled this chapter a toolbox. To maintain the analogy, we understand the answer to the question as an extensive toolbox with a mix of existing tools (e.g., scenarios, personas) and many empty

compartments. We tried to fill three of these compartments with new tools as well as extensions of existing ones.

As part of the Paris case study, we developed a *method to localise (archetypical) scenarios* to make scenario-based design approaches more accessible as well as a checklist to select and evaluate existing scenario sets on their suitability. Next, we proposed a *persona- and synthetic population generation method* to work with future urbanites and tested it in agent-based scenario simulations. Finally, we developed a *tool to support decision-making* with a particular focus on integrating uncertainties via scenarios, enabling people-centredness via personas, and highlighting complex interactions while acting as a platform to stimulate exchange between subject matter experts. We replicated the core methods in Cairo and extended it via a more comparative framework for three possible interventions. The following section summarises the three methodological contributions, followed by an overall discussion.

1 | Scenario localisation method: The first methodological contribution is the localisation of scenarios, developed in the context of Paris and replicated in Cairo. Building on scenario methods, we propose a formalised and structured approach to select an existing scenario set or archetypical scenarios, supported by a checklist, which then can be localised and enhanced via an iterative approach resulting from dynamic system modelling – in our case people, infrastructures, and services as three

layers of the UMS. This method shall enable a wider and easier uptake of scenario-based approaches as well as providing an option to apply it to complex systems.

Contrast to existing works: Existing methods are primarily developing scenarios from scratch, with an extensive list of methods to do so. Compared to this, we are proposing a method to create scenarios based on existing scenarios. These, as shown through works on archetypical scenarios, are often relatively similar and can significantly reduce the needed resources while still ensuring a solid process, enabled via the proposed checklist. Further, most scenarios created today are either generic or in few cases, specific to one context. In contrast to these restrictive approaches, we propose an iterative localisation method which permits to localise generic scenarios to different socio-spatial contexts in a structured manner. To our knowledge, this has not been proposed so far.

2 | Future synthetic populations' generation: The second contribution is a scenario-based method to create a set of future synthetic populations as direct response to the people-layer of the UMS, developed in Paris and replicated in Cairo. By clustering personas from census and mobility surveys, a set of distinct personas is created that can be reweighted to match future values for uncertainties such as the number of cars per capita. This method permits the structured integration of future uncertainty with focus on socio-demographic trends in quantitative methods such as activity-based mobility modelling.

Contrast to existing works: Detailed methods for the replicable generation of synthetic populations have created. However, they are so far not integrating future uncertainties. We propose a method which permits to do so in a structured approach.

3 | Urban impact assessment tool: The third contribution is an interactive scenario-based tool that allows, in a collaborative setting, to rapidly assess the impacts of potential mobility interventions across indicators and futures with a special focus on heterogenous impacts on different groups of people (qualitative personas). It shall enable advancing and mainstreaming foresight-based and people-centred approaches in decision-making and design processes as well as acting as preparatory step of more advanced approaches.

Contrast to existing works: Various tools and methods for assessment exist. However, to our knowledge, no open and accessible methods are permitting to integrate uncertainty. Furthermore, most assessment frameworks are part of larger frameworks and 'black box' approaches. In contrast to these, our proposed tool is fully replicable, adaptable, and permits the integration of future uncertainties. The flexibility of the method, e.g., by making the process more or less complex by hiding/showing parameters and components, further enables to adapt the method to different use cases and application fields outside of urban mobility solution design.

Aside from these specific contributions, some general considerations shall be highlighted. Throughout the case studies, *reproducibility, use of open data, and open-source tools were paramount*. Only in few cases, a choice was made to work with not directly accessible data to ensure better model quality. In these cases, the data is available on request. The idea behind this is simple: We argue that the propositions made throughout this chapter have a value for certain applications. But we acknowledge that they are incomplete and have various potentials for improvement which can only be achieved in a collective manner. This chapter provides rather a snapshot than a final outcome. Or to put it in other words: The toolbox remains with many empty compartments as well as tools that need further evolution.

Secondly, an apparent contrast exists between the decision-support tool and the agent-based simulations. On the one hand, this was on purpose to test proposed methods across disciplines and approaches and highlight the contribution at a meta-methodological level. On the other hand, the two approaches could come together as outlined earlier. *The tool is envisaged to precede agent-based simulations, make their parameters more accessible, and collect inputs in a more tangible manner.* While currently still limited by computing power to make it user-friendly, the tool and simulations are envisioned as integrated steps of a holistic and accessible approach of designing more people-centred and sustainable solutions for UMSs.

Finally, the focus of this chapter remains on urban mobility systems. As became clear throughout, systems lack clear boundaries and are highly intertwined with urban planning, housing, and many other fields. The title of this doctoral project is, therefore, purposely referring to urban systems and an application to mobility. We postulate that developed tools could find application in other urban systems, notably housing and energy systems, and envisage the testing thereof in the future.

As nature abhors a vacuum, we humans abhor uncertainty.

Irvin D. Yalom, Existential Psychiatrist

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6 CONCLUSION: MANY FUTURES, FEW ANSWERS

In this work, the future has taken the centre stage. Or more precisely, a *multitude of possible futures and their integration in design processes*. In the last chapter, we return to the present and discuss the few answers which arose from the doctoral project. First, a short summary, structured by responses to the research questions, and discussion of contributions initiates this chapter. Next, a few recommendations are formulated before focusing on limitations and identified potentials for future works. Figure 62 shows the link to preceding chapters, zooming out to the same level as the introduction.



Figure 62: Diagram with highlighted conclusion, building on Chapters 2-5 (CC BY 4.0)

6.1 Summary

This work set out to find support methods for the integration of future uncertainties into design processes of people-centred mobility solutions for urban systems, applied to urban mobility and tested in Paris and Cairo.

To get there, we started with a literature review of different conceptual fields: *complex system studies and futures studies*, as well as the domain-related fields of *urban and mobility studies*. This provided the basis to establish a mixed method, case-study based research approach, using Paris as a socio-geographical context to co-create and iteratively apply, test, and improve models and methods. To test their utility and prove partial generalisation, we replicated and validated the developed toolbox in the context of Cairo. The work resulted in two integrated models for future UMS, and three methods to 1) localise future scenarios, 2) integrate demographic and behavioural changes via scenarios in agent-based simulations, and 3) support rapid assessment via an interactive decision and design support tool.

While remaining initial findings with a set of limitations, the conducted work permits us to respond to the formulated research questions. We do so in the next paragraphs, before focusing on the contributions, recommendations, and directions for future work.

Main RQ: How can design processes of people-centred mobility solutions for future urban systems be supported?

We identified scenarios as established and methodologically solid intermediary design objects which are easy to communicate and use in participatory settings while permitting a structured integration of future uncertainty via trends and uncertainties. While existing scenario-based approaches were identified as sufficient, a number of specific challenges were identified and led to a number of gaps and linked sub-questions.

Supporting RQ 1a: How can urban mobility systems be modelled?

The first sub-question targeted the modelling of UMSs. As they shall be adapted via the use of future scenarios, a systemic understanding thereof, as well as a structured model, were identified as crucial but missing elements. Via literature, interviews, and workshops, a UMS model was created, constituted of various elements, grouped into three key layers: People > Infrastructures > Services. With diverse existing works on infrastructures and primarily rational-reactive mobility services design, we focused thereafter on *people as the key potential for conceptual and methodological extension*. This choice was motivated by the role of people as the first changing and most impactful layer of urban mobility systems.

Supporting RQ 1b: How can urban mobility system futures be modelled?

The next sub-question focused on the integration of futures in UMSs. First, a scenario-based approach was identified as most promising solution. The *futures cones model* was revised to support the co-creation of futures. Next, scenarios were overlaid with the UMS model, leading to a set of combinations. To simplify the dynamic and complex system interactions, we identified a simplified order of influence, starting with changes within the dimension of *People*, followed by adaptation of *Infrastructures* and finally the most fast-paced modification of mobility *Services*. This resulted in a framework for scenario-based design of UMS futures.

Supporting RQ 1c: How can future urbanites be modelled?

As mentioned above, the modelling of people, in our case those in urban areas, appeared as most underdeveloped and with the highest potential. The modelling of these *future urbanites* has been tackled via a two-pronged approach, combining a primarily qualitative, *persona-based approach*, and a quantitative method focusing on *proto-personas* and their use to adapt *synthetic populations*. The latter were identified as promising intermediary design objects as they are compensating limitations of qualitative methods due to their ability to ensure statistical representativity for the present, as well as being key inputs of agent-based simulations, one of the methods tested within the doctoral project. The integrated approach permits to enable collaboration across disciplines that already work or want to work with different models representing people, feed different existing methods such as qualitative design or quantitative modelling and simulation and extend them via the futures dimension – to our knowledge not existing so far.

Supporting RQ 2a: How can future scenarios be localised?

Aside from the primarily conceptual research questions 1a-1c, many methodological questions arose from which we chose three to focus on in this work. Each choice resulted from a mix of identified gaps and potentials, as well as the necessity of the case studies. The first resulted from the oversupply of existing archetypical or general future scenarios but *their prevalent lack of local context* – a crucial dimension for the

work on local UMSs and place-based solutions. The application of the future UMS model, fed by inputs from local, mostly grey literature, surveys on uncertainties and trends' importance and likelihood, an inventory of uncertainties and trends for mobility, as well as structured expert workshops, permitted a fast and effective approach to localise in our case archetypical scenarios.

Supporting RQ 2b: How can future uncertainties be integrated in synthetic populations?

A more technical research gap arose when trying to apply the scenario-based approach to agent-based simulations. To our knowledge, existing works of future synthetic populations focus on infrastructure evolvments and/or linear scaling of population size. These appeared insufficient due to lacking approaches to integrate uncertainties. As a response, we propose a scenario-based approach, using again future trends and uncertainties, as well as personas, *to adapt synthetic populations to different futures*.

Supporting RQ 2c: How can future uncertainties be integrated in agent-based simulations?

The last question focuses on the subsequent step of synthetic populations. While changes in future urbanites constitute a fundamental difference for simulations of future UMSs, other changes in the infrastructure or services layer are possible. The main contribution of this work is on *the integration of future uncertainties via adapted synthetic populations* representing the people layer of UMS. Even if infrastructure and spatial elements are not directly modelled, the linear or location-dependent scaling or reduction of the synthetic population has significant impact on the spatial dimension. Additionally, we integrated trends via the simulation of planned projects (e.g., Grand Paris Express), as well as uncertain future transport development (i.e., a BRT service on Cairo's ring road). The answer to this question is thus partial and focusing on the people dimension with minor contributions to the other dimensions. However, significant potentials for further works have been identified, especially to develop methods building on such synthetic populations and adapting, for example, the spatial UMS layer accordingly.

6.2 Discussion of contributions

The contributions of this work are strongly linked to the responses to each of the research questions. To delve a bit further into them, we use the initial conceptual framework (Figure 63) and use the three dimensions to discuss the contributions. The first part is on the structured modelling of urban systems, in particular that of urban mobility systems. While inherently incomplete and an abstracted version of a much more complex reality, we argue that the model permits to work with present and future urban mobility in a structured manner. In particular, the three categories and their relationship permit to model future changes.

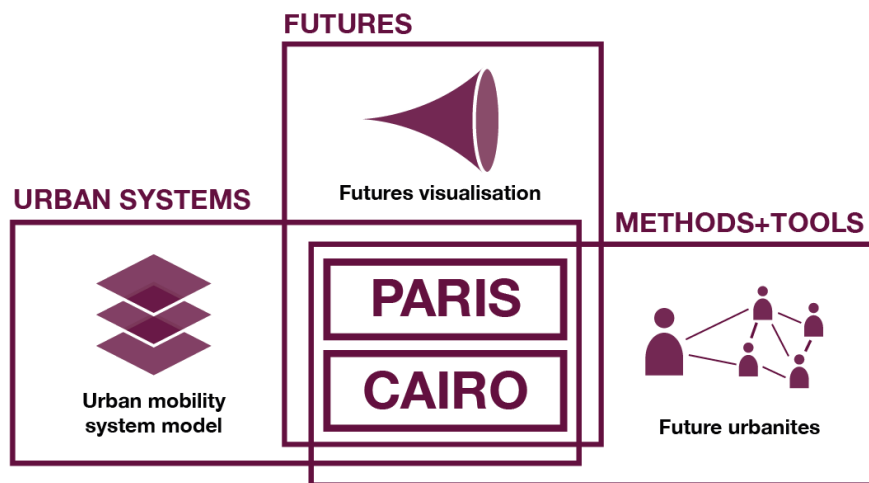


Figure 63: Diagram of tripartite conceptual and methodological contributions (CC BY 4.0)

This brings us to the next element of futures. The principal theoretical contribution has been the visualisation and extension of the futures cone. While the futures cone exists for a while, it missed a detailed review and description from a scientific perspective. Further, we added three new components and clarifications, resulting in a scientific and methodological contribution which has found already ample replication and uptake.

Finally, most of our methodological work focused on future urbanites; trying to find solutions to how future urbanites can be integrated in design and planning works of today. Three methodological contributions resulted from this. The central one is the *joint approach of personas and synthetic populations* – a combination to our knowledge not explored yet – with promising findings and uptake within and outside of this doctoral project.

We postulate that the proposed framework and the few contributions to a larger toolbox for UMS solution design, can benefit the design of solutions that are *more futureproof and people-centred* than those designed without a structured consideration of future uncertainties. However, a number of limitations remain or resulted from the work.

Foremost, we repeatedly referred to collaborative design and processes. However, while we focus on co-creation, the work does not integrate the collaboration with users as such. This is not the case because it is not deemed important but as necessity to focus on areas with most identified potential and limited resources. Instead, co-creation has taken another role in this work. The collaborative research with partners of private and public sector as well as various academic partners from different disciplines have been fundamental for a holistic perspective on UMSs. Further, the specific collaboration between qualitative design methods and quantitative simulations methods has led to various benefits within and outside this project.

In general, the work with uncertainty, and uncertain futures, will always remain full of theoretical and conceptual limitations. While this is acknowledged, we postulate that the adequate response to this is finding better tools and methods to integrate the future uncertainty in today's practice and continuously evaluate and improve such methods when more or better information are available. This is strongly linked with the *challenge to validate prospective works*. Thus, we focused on the validation of a positive contribution of the proposed methods to today's design and decision-making

processes as perceived by the target audience instead of validating the actual result or realisation of one scenario or another.

While this proved successful in many situations, we encountered especially one context where our method faced limitations which are difficult to overcome. In New Cairo, economic and political dynamics linked to the housing market seem too dominant to permit our approach to create realistic results. In other words, our proposed methods require a certain freedom from external forces to reproduce system dynamics which can be modelled and integrated in the process. When planning and investment choices are largely not responding to the observed changes in society and the related needs, the layer-by-layer model to adapt UMSs does not work well. However, by zooming out again and focusing on the larger Cairo context and integration of related uncertainties via the scenarios, it has been possible to integrate these dynamics within the proposed framework. In conclusion, the proposed conceptual and methodological contributions seem overall valid, utile, and replicable for the design and testing of urban mobility solution. However, more validation, uptake in practice, and replication within other methods are needed to make generalisations on a higher level.

On a practical side – representing the last step of the DRM method’s iteration – the work of this project has been widely communicated, mostly to obtain regular feedback and validation of partial works. A number of publications resulted which are listed below. Three additional journal papers on the two application cases and the online tool are currently in preparation.

Journal papers

1. **Gall, T.**, Vallet, F., and Yannou, B. (2022) How to visualise futures studies concepts: Revision of the futures cone. *Futures*, 143/103024. <https://doi.org/10.1016/j.futures.2022.103024>
2. **Gall, T.**, Hörl, S., Vallet, F., and Yannou, B. (2023) Integrating future trends and uncertainties in people-centred urban mobility design via data-driven personas. *European Transport Research Review* [forthcoming]

Conference papers (peer-reviewed)

3. **Gall, T.**, Vallet, F., Ben Ammar, M., and Yannou, B. (2023) Designing solutions for uncertain futures: A checklist for choosing suitable scenarios. *ICED23*.
4. **Gall, T.**, Vallet, F., and Yannou, B. (2023) Comment concevoir des systèmes de mobilité urbaine pour les citoyens du futur ? *Épique* 07/2023.
5. **Gall, T.**, Chouaki, T., Vallet, F., and Yannou, B. (2023) Un cadre basé sur les scénarios du futur au service de la simulation multi-agents de la mobilité urbaine de demain. *s.smart colloque*.
6. Vallet, F., Hörl, S., and **Gall, T.** (2022) Matching Synthetic Populations with Personas: A Test Application for Urban Mobility. *Proceedings of the Design Society*, 2, 1795-1804. <https://doi.org/10.1017/pds.2022.182>
7. **Gall, T.**, Vallet, F., Douzou, S., and Yannou, B. (2021) Anticipate, Adjust, Adapt: Managing Sustainability Transitions through multiple Scenarios of Urban Mobility Futures. 49th European Transport Conference, online, Sept. 2021.
8. **Gall, T.**, Vallet, F., Douzou, S., and Yannou, B. (2021) Re-defining the System Boundaries of Human-Centred Design. *Proceedings of the Design Society*, pp. 2521-2530. <https://doi.org/10.1017/pds.2021.513>

Other conference papers

9. **Gall, T.**, Vallet, F., and Yannou, B. (2021) Co-Creating Sustainable Urban Futures: An initial Taxonomy of Methods and Tools. ISOCARP 56th World Planning Congress 'Post-Oil City – Planning for Urban Green Deals', Doha, Nov. 2021.
10. **Gall, T.** (2021) Working with multiple Scenarios: Revising the Futures Cone. Conference paper, AESOP YA Conference 2021 in Tirana, Albania, March 2021.

Other publications

11. **Gall, T.**, Vallet, F., Reyes, M., Hörl, S., Abdin, A., Chouaki, T., and Puchinger, J. (2023) Sustainable Urban Mobility Futures: Transdisciplinary Challenges, Trends, and Pathways for Sustainability Transitions. London: Palgrave Macmillan/Springer [in press]
12. **Gall, T.** and Allam, Z. (2022) Strategic foresight and futures thinking in urban development: Framing planning perspectives and decolonising urban futures, p. 10-19. In: Peric, A., Permezel, M., Stott, M., and Woo, A. Future Cities Series: Practical planning guidance for innovative, resilient and inclusive cities of the future: Discussion paper 1. Nairobi/The Hague: UN-Habitat and ISOCARP. Available at: <https://hal.archives-ouvertes.fr/hal-03832837/>

6.3 Recommendations for practice and research

This work aimed foremost on methodological contributions. In this sense, a general – and personal – learning is that everything can be designed and that structured approaches from the field of design studies can significantly contribute to this process and should find broader uptake in other fields, especially those dealing with ample normative design and planning activities, such as urban and regional planning and design. So far, a large part of design studies focuses on products and services. This work integrated or touched repeatedly upon the design of policies. Thus, the extension towards this field is another systemic and predominantly academic recommendation.

For practice, the recommendation is two-fold yet straightforward. The future is uncertain and ample methods exist already to integrate this in the work today. To address the resource-intensity, some simplifications are possible through reuse and adoption of archetypical and existing scenarios. For example, working with archetypes can facilitate adapting scenarios across multiple dimensions. Even simpler approaches such as the 2*2 matrix exist. This method can be used if only two critical uncertainties are considered and still permit an integration of future uncertainties across design and decision-making methods.

In either case, the potential gain of the *structured consideration of future uncertainties* appears to consistently outweigh the needed resources to integrate foresight in day-to-day practice. Increasing complexity and pace of change, matched with additional uncertainties resulting from climate and political crises, and a conclusive negative track-record of faulty past assumptions about the future, make it very probable that the resources invested into foresight will be easily recovered. Additionally, any further uptake and replication lead to more data and insights, thus permitting urgently needed structured evaluation of long-term impacts and resulting benefits for foresight.

Secondly, the work with scenarios showed across the application cases that significant potential gains of environmental, social, or economic performance do foremost not origin from new technologies such as AVs. The largest differences of,

for example, emissions or accessibility, result from *where people live and work* and what their *behaviours* are. This is followed by the *increase in efficiency* of personal vehicles, and only then the differences between different solutions – of whatever type – show a recognisable impact on a system level. Thus, a more general recommendation for practice and public policymaking might be *a reorientation of focus on behaviours and spatial distributions of functions instead of technological advances* (cf. Dyson and Sutherland, 2021).

6.4 Directions for future research

As already pointed out throughout, the section on future research could be as long as the dissertation itself. However, we want to focus on a few key elements that reappeared consistently and are perceived to bear more potential than what has been possible in this doctoral project. These are elaborated at three levels. First, the immediate continuations of the conducted works which are either already ongoing, planned, or hopefully find some continuation elsewhere. Secondly, more conceptual continuations of pathways we explored during the past years but have not been walked until the end. Lastly, some larger and higher-level reflection on uncertainty, sustainable and people-centred urban mobility systems and co-creative as well as place-based approaches.

To start, there are a set of immediate continuations of the described work. These include, for example, the continuous improvement of synthetic populations for Cairo, testing more possible interventions or different *uncertainty constellations for the scenarios*, as well as higher sample sizes for computationally heavy works to improve accuracy of simulations. The same applies for the design and decision support tool. While it has proved to provide different potential benefits, such tools can only be exploited if used repeatedly in real-life situations, updated and extended constantly by reacting to expressed needs, as well as extending it into a more user-oriented platform that balances between keeping an editable and open-source framework to avoid any ‘black box’ character while maintaining simplicity and accessibility across user profiles.

Other potential continuations include further *exploitation of personas in the simulation context*. For example, current agent-based simulations – as well as other models with similar approaches, assume a single utility function for everyone. This means, that every agent has, for example, the same value of time, money, and ability or willingness to walk. While the utility function itself is conceptually a core area of further refinement, it also bears potential to be calibrated better to match closer the observed reality (by possible other measures) and include other factors, such as comfort. The persona-based approach bears a specific potential for this. The utility function cannot be calibrated for everyone individually. However, for example, 16 personas can be the basis for a set of utility function calibrations which might as such better match observed reality – assuming that the personas successfully cluster people with similar preferences and characteristics.

A last specific extension is adding another component that combines qualitative and quantitative approaches but this time focusing on the scenario development. Various quantitative approaches exist to deal with uncertainty and many qualitative and partially quantified such as ours – exist for scenarios. We identified the possibility to combine the concepts of uncertainties with defined extremes, means, and distributions (e.g., normal, uniform) across the possible range. Combined with Monte Carlo simulations, this can be used to generate multi-uncertainty combinatory spaces

which, together with concepts such as the 2*2 scenario matrix and a stochastic selection approach, could provide an alternative approach to test possible and likely scenarios. The advantage is that it reduces the needed input to uncertainty-specific information and thus permits, for example, working with experts of different fields who only define their expected possibility space for their field of knowledge. A proof of concept has been already created but is not yet at a level to be integrated here.

On a more general level, we focused on people, or urbanites, as one of the three layers of urban mobility systems. More approaches exist already for modelling infrastructure developments, e.g., land-use change models. For service adaptation, some approaches exist but significant gaps exist as well. Thus, a large set of uncertainty-integration of these two layers, as well as their joint approach – possibly linked to a dynamically-linked development over time, similar to that of Land-Use/Transport Interaction models. On a procedural level, there remains ample space for improvement in communicating concepts from one field to another. Any type of advancements in this direction, regardless of it being glossaries, standards, or joint working groups – such as we had the opportunity to exploit at the Anthropolis Chair – permit to find new solutions without reinventing the wheel but by looking left and right what already exists and how it might be able to respond to open questions in the respective fields.

To complete this section, we are referring to the choice of words in the title. While our focus was clearly on urban mobility, we speak of urban systems. To quote Meadow's again: 'There are no separate systems. The world is a continuum. Where to draw a boundary around the system depends on the purpose of the discussion.' (Meadows, 1999) We postulate that the majority of this work's contribution *can be applied to urban systems of various types* and delineations – urban mobility being solely a particularly interesting and rich application context. Thus, further developments of extending or replicating some of the approaches in other complex socio-technical sub-systems, such as *urban energy, housing, or job markets*, could be an interesting and promising endeavour.

This brings us to the last paragraph and a general reflection. My career started in one discipline, became multi-disciplinary before shifting between inter- and trans-disciplinarity in the past couple of years. Inspired by a researcher in Lisbon, today I prefer the expression *undisciplined*. While subject matter experts and specialists remain crucial, the world is full of wicked problems – a trend without any tendency of slowing down. To address them, scientific contributions are paramount. Yet, these are rarely found in a singular discipline or by using a stand-alone method. Instead, result-based, applied, and data-driven approaches are needed. These require pragmatic approaches. Selecting theory, concept, method, and tool based on the problem. I conclude by arguing that the most fundamental future research potential of sustainable urban development lies foremost in *undisciplined, applied, collaborative action research* conducted with receptive ears and eyes and the willingness to share openly with others.

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ANNEXES

AN.1: Informed consent templates

English and French templates for interviews with external participants

Project title: Scenario-based design of people-centred mobility solutions for urban systems

INTERVIEWEE PRIVACY FORM

This research is conducted to improve the understanding of the urban mobility system and generate insights in how past and future transitions can contribute to people-centred and sustainable urban mobility in a local context. It is conducted as part of the doctoral project of Tjark Gall, titled 'Co-creating people-centred futures for place-based transition design of complex adaptive socio-technical systems: The case of urban mobility' conducted at the CentraleSupélec and IRT SystemX.

Procedures: You participate in an interview of *45-60 minutes*. You will be asked questions related to your professional expertise of urban development, transport, and/or mobility.

Risks: There are no obvious physical, legal, or economic risks.

Confidentiality: Your privacy will be protected to the maximum possible extent. This research project may involve *audio recordings* of interviews with you. *Transcribed segments* from the audio recordings *may be used* in published forms. The media created or collected is stored in a secure location and will be destroyed within latest ten years of the initiation of the study. *You can always request a copy of your records.*

Right to withdraw & questions: Your participation is voluntary. You may stop participating at any time. The data you provided before you stopped participating will be processed in this research; no new data will be collected or used.

Statement of consent: Your signature indicates that you have read this form; your questions were addressed, and you participate in this study. You receive a signed copy.

I agree to participate in the research project led by Tjark GALL [tjark.gall@centralesupelec.fr]. The purpose of this document is to specify the terms of my participation in the project through being interviewed.

1. I have been given information about the project. The purpose of my participation as an interviewee is clear.

2. My participation as an interviewee is **voluntary**.

3. I _____ (do / do not) allow the **audio recording of the interview**.

4. I have the **right not to answer** any of the questions.

5. **If I wish so**, the researcher will **not identify me by name or function** in any reports using information obtained from this interview. My confidentiality as a participant in this study will remain secure. I agree to be referred as:

PLACE, DATE

PLACE, DATE

NAME PARTICIPANT

NAME INVESTIGATOR

SIGNATURE

SIGNATURE

FORMULAIRE DE CONFIDENTIALITÉ

Cette recherche vise à améliorer la compréhension du système de mobilité urbaine actuel et à produire des connaissances sur la manière dont les transitions passées et futures peuvent contribuer à une mobilité urbaine plus durable et centrée sur les personnes dans un contexte local. Elle est menée dans le cadre du projet doctoral de Tjark Gall, mené à CentraleSupélec et à l'IRT SystemX. Le projet est intitulé « Co-crée des futurs centrés sur les personnes pour une conception de transition basée sur le lieu de systèmes socio-techniques adaptatifs complexes : le cas de la mobilité urbaine »

Procédures : Vous participez à un entretien de 45 à 60 minutes. Des questions liées à votre expertise professionnelle en matière d'aménagement urbain, de transport et/ou de mobilité vous seront posées.

Risques : Il n'y a pas de risques physiques, juridiques ou économiques évidents.

Confidentialité : Votre confidentialité sera protégée au maximum. Ce projet de recherche peut impliquer des enregistrements audios d'entretiens avec vous. Toute transcription et utilisation ultérieures seront anonymisées. Les segments transcrits des enregistrements audios peuvent être utilisés dans des documents publiés. Les supports créés ou collectés sont stockés dans un lieu sécurisé et seront détruits dans les dix ans suivant le début de l'étude. Vous pouvez toujours demander une copie de vos dossiers.

Droit de rétractation & questions : Votre participation est volontaire. Vous pouvez cesser de participer à tout moment. Les données que vous avez fournies avant de cesser de participer seront traitées dans cette recherche ; aucune nouvelle donnée ne sera collectée ou utilisée.

Déclaration de consentement : Votre signature indique que vous avez lu ce formulaire ; vos questions ont été abordées et vous participez à cette étude. Vous recevez une copie signée.

J'accepte de participer au projet de recherche mené par Tjark GALL [tjark.gall@centralesupelec.fr]. L'objet de ce document est de préciser les modalités de ma participation au projet par le biais d'un entretien.

1. J'ai reçu des informations sur le projet. Le but de ma participation en tant qu'interviewé est clair.
2. Ma participation en tant qu'interviewé est **volontaire**.
3. _____ (J'autorise / Je n'autorise pas) l'**enregistrement audio** de l'entretien.
4. J'ai le **droit de ne pas répondre** à n'importe quelle question.
5. **Si je le souhaite**, le chercheur **ne m'identifiera pas** par mon nom ou ma fonction dans les rapports utilisant les informations obtenues lors de cet entretien. Ma confidentialité en tant que participant à cette étude restera sécurisée. J'accepte d'être référencé comme :

LIEU, DATE

LIEU, DATE

NOM PARTICIPANT

NOM ENQUÊTEUR

SIGNATURE

SIGNATURE

AN.2: Interview guidelines

This section describes the different conducted interviews, provides the underlying interview guidelines, and – in parts complementary to the main text – describes its outcomes.

AN.2.1: Interview guideline for Chair context scoping interviews

We conducted five semi-structured online interviews between 25 May 2021 and 30 June 2021. Each interview involved one or two representatives from the institutions and lasted between 0:45h and 1:45h. The leading questions were the following:

- What are some of the major challenges which [company] will face over the next years/decades?
- What projects about future projections in [company] were you involved in or know about?
- Can you tell if the elements of the futures cone (scenarios, backcasting...) apply to some projects and if yes, how?
- How do you think could strategic foresight, futures studies, and scenario planning contribute to current and upcoming challenges of [institution]?
- What would you like to know about the future?
- What type of stakeholders or experts would you like to work with on that topic?
- How can the work on urban mobility futures of the Anthropolis Chair contribute to your work and how would you like to be involved in the next few years? These can be regular check ins and exchanges, participation in workshops around the topic within the chair, or also the facilitation of workshops within [institution].
- Is there anything else that you would like to comment on that we haven't discussed today?
- Is there anyone you can recommend us to talk to additionally?

Each interview was recorded, summarised and the content was checked by the respondents via e-mail. The main outcomes are captured in a qualitative discursive manner.

AN.2.2: Interview guidelines for expert interviews

An ever-increasing number of people lives in more and larger urban areas, moving faster, farther, and more frequently than ever before. The urban mobility systems that allow them to get around lead to various social, environmental, and economic challenges, such as pollution, resource scarcity, or inaccessible job markets and basic urban services. How can we design pathways for urban mobility systems that enable and lead to more sustainable and inclusive urban futures?

Situated at the Industrial Engineering Laboratory of CentraleSupélec, University Paris-Saclay, and the Anthropolis Chair of publicly co-funded research institute IRT SystemX, the doctoral research project applies a holistic systems perspective to analyse how today's urban mobility systems can become more sustainable and people-centred. A particular focus lies on the empirical validation of the role of co-creating and localising futures as part of the transition design process.

The three expected outcomes are (1) a **heuristic model of urban mobility** as a complex adaptive socio-technical system, (2) a way to **analyse and enable the transition** of such systems, as well as (3) the empirical validation of sub-processes of the **transition design process**.

This can contribute to a more systemic and integrated understanding of today's rather siloed urban mobility systems and transitions thereof. Thus, it builds a strong foundation for the design of future services, products, and policies, providing explicit recommendations for practitioners and policymakers alike.

This set of interviews and workshops serves a dual purpose:

- The **expert validation** and **nourishment** of two models of urban mobility and its transition processes.
- The data collection for a case study of the **urban mobility system of metropolitan Paris**.

Objectives (internal only/in general through each of the cases):

- Understand/compile system components/architecture/transitions/...
- Understand/define current system state
- Understand/describe past transitions/drivers/...
- Understand/describe present-future transitions (multiple directions/scenarios?)
- (Explain barriers/drivers for transitions; test impact of co-creation/place-based/futures)

Thank you for taking the time to talk to me today. Your responses today are very important for my doctoral research. My research is conducted at the Laboratoire Génie Industriel of CentraleSupélec and IRT SystemX. Additional to the core field of complex system engineering, my own background is urban studies, thus I combine elements from mobility, transport, and urban development. I hope that my research contributes to a more systemic understanding of the urban mobility systems and their transitions. To get there, I rely on literature and case studies, but also your and other experts' input. Ultimately, I am trying to find out how we can design pathways for urban mobility systems that lead towards a more sustainable and inclusive urban future.

—

Now just some small formalities. To fulfil data privacy requirements and so on, I brought a small form with a few information [hand over form, introduce different parts].

Important is that you indicate if I can or cannot record this interview. This would be very helpful to transcribe parts of the interview later. Of course, I'll anonymise all responses and ensure that there is no way to identify you as the interviewee (except you wish otherwise of course).

[if non-English native: My research is conducted in English, therefore, it would be great if we can do the interview in English as well to simplify the transcription etc. However, you may at any time switch to French for parts or the rest of the interview in case that would allow you better to share your thoughts].

So much from my side. Could we start with a little introduction on what you are primarily working on and what your role is? Just in a sentence or two.

Prefect, thank you. So, can I refer to you as _____ [fill in possibly prior to interview, e.g., transport planner at a public transport operator]

—

Great. I'll start the recording [start recording] and we can get going.

—

Let's start with the first part of the interview:

(Part 1): What is part of an Urban Mobility System? [30 minutes] TIME 13:35

[supplementary material 1]

I see urban mobility as a system constituted of physical elements (e.g., infrastructure), social and governance elements (e.g., land use, regulations), travellers/users, vehicles, and more, like it is visualised here in the graphic.

You can also see the three parts of the interview. We start talking about the present, then look at the past, and finally forward into the future.

—

1a) From your personal experience and perspective as a [transport planner], what are some of the most important elements of an urban mobility system? Additional, or more in detail to those which are already shown here. Feel free to write or sketch things directly on the paper as well.

1a.FQ1: What about infrastructures, physical, non-physical, data, behaviours, policies? Could you give some specific examples?

1a.FQ2: How would you prioritise the elements? Why are they the most important ones?

1a.FQ3: Are they these the key elements everywhere? Are the elements the same in Paris and Rouen, for example?

[try to reformulate: If I understood correctly, ...]

—

Now I would like to introduce the example of the UMS in Paris and its environment and talk about the system in general as well as the case of [public transport/MaaS/planning]. Here you can see a map of Paris and its environment, as well as the Plateau Paris-Saclay.

[supplementary materials 2 & 3]

1b) First, could I ask you to reflect on the geographical extent of what you consider the UMS of greater Paris? What is part of it, and where does it end? Which governance or geographical scale is most adequate? The city of Paris, the Metropolis of Greater Paris, the Île-de-France, even more, for example incorporating Rouen, or something in between?

1b.FQ1: Why do you include/exclude xyz?

—

1c) Could you describe how you as a [e.g., transport planner] see today's UMS in the case of [Paris/PPS]? [If expert for one of three topics]: In particular, focusing on to the elements and actors connected to [public transport, MaaS, spatial planning].

1c.FQ1: What are the most important elements in [Paris], physical and non-physical? Why are they the key elements?

1c.FQ2: Who are key actors who have an influence on the UMS? Who has most influence? Who should have an influence but is not enough involved?

1c.FQ3: Based on your experience, what is the primary purpose of the urban mobility system? Whom shall it serve? How can we measure its quality, meaning the fulfilment of its purpose?

1c.FQ4: Would you describe the current system as sustainable and centred on the people (both users and others)? Why, why not? Which components are contributing most to it being (not) sustainable and/or people-centred?

[try to reformulate: If I understood correctly, ...]

Part 2: Past transitions [12 minutes] TIME 14:05

Let's most to the second part. My goal is to better understand how the UMS changes over time to find the right levers and tools to impact future urban mobility. Therefore, we can have a quick look at how the UMS looked in the past.

Here you can see a timeline for greater Paris.

[supplementary material 4].

You can see for example the start of Velib, the inauguration of Anne Hidalgo, the move from the university Supélec to the Saclay Plateau and more... I would like you to choose one year in the past for which you think you can respond well to similar questions like I asked before. E.g., what were key elements or central actors. Which year do you feel most comfortable with? It can be 5 or 50 years ago.

—

2a) Could you describe how you perceive the UMS in the year YEAR in the case of [Paris/PPS]? [If expert for one of three topics]: In particular, focusing on to the elements and actors connected to [public transport, MaaS, spatial planning].

2a.FQ1: What were the most important elements in [Paris], physical and non-physical? Why were they the key elements?

2a.FQ2: Who were key actors who had an influence on the UMS? Who had most influence? Who should have had an influence but was not enough involved?

2a.FQ3: Based on your opinion, what was the primary purpose of the system? Whom should it serve?

2a.FQ4: Would you describe the past system as sustainable and centred on the people (both users and others)? Why, why not? Which components were contributing most to it being (not) sustainable and people-centred?

[try to reformulate: If I understood correctly, ...]

—

2b) What happened between the UMS in YEAR and today? Can you describe a bit – mostly in your field of [transport planning] what changes took place?

2b.FQ1: What catalysts or barriers?

2b.FQ2: Who were key stakeholders?

2b.FQ3: What factors had the highest impact?

2b.FQ4: Were there failed transitions? For example, projects that were supposed to have a significant impact on the urban mobility system but did not end up successful?

[try to reformulate: If I understood correctly, ...]

Part 3: Future transitions [12 minutes] TIME 14:17

So far, we looked at the current moment, or the past. Now let's investigate possible futures, let's say in 2040. Take a moment to think about how old you will be, or maybe your children (in case you have or will have some). It's only 18 years from now.

3a) What do you think might be different by then? Your answers can be very open and speculative, and there is no need to provide responses that all fit together. For example, you could say that there might be either no more cars or only autonomous cars.

3a.FQ1: What could be the most important elements in 2040, again physical and non-physical? Why would they be the key elements?

3a.FQ2: Who might become the key actors who will have an influence on the UMS? Who will have most influence? Who should have the highest influence in the future?

3a.FQ3: Based on your opinion, what will be the primary purpose of the system? Whom shall it serve? How could we measure its quality, meaning the fulfilment of its purpose?

3a.FQ4: Would you describe the future system as sustainable and centred on the people (both users and others)? Why, why not? Which components would contribute most to it being (not) sustainable and people-centred?

[try to reformulate: If I understood correctly, ...]

3b) What do you think are some of the key changes within your field that will impact the development until 2040?

3b.FQ1: What would need to happen to get to the preferred future urban mobility?

3b.FQ2: What risks are there? Which development could bring negative changes?

3b.FQ3: Which stakeholders will play the most important roles?

[try to reformulate: If I understood correctly, ...]

Great, these were all the questions. I will conduct more interviews, and together with other sources produce a report and publications from it. Are you interesting in receiving the outcomes of the study?

Perfect. Then, would you like to share some things or thoughts that did not fit into any of the previous answers?

Otherwise, don't hesitate to send an email or call if something comes to your mind...

Also, if you can recommend some reports or articles that complement our conversation, it would be great if you could send them to me.

Lastly, if you have some ideas on who else I should interview for complementary insights, I would be glad to be referred to them. Do you have anyone in mind?

Thank you very much. Do you have any other questions on your side?

Yes/no, ... Then I'll stop the recording. [stop recording]

AN.3: Workshops and interview descriptions

This annex describes key workshops and a set of expert interviews that have been conducted and which are referenced throughout the dissertation.

AN.3.1: Workshop on explorative future mobility situations, May 2021

On 19 May 2021, members of the Anthropolis Chair organised a workshop on human-AV relations across territories as part of the Third Annual Grand Rendezvous of the Robomobile Life Future Workshop, an initiative by the French Ministry of the Ecological Transition (Figure 64). Autonomous vehicles (AV) will impact urban mobility futures. Yet, its role largely depends on the spatial and societal context. Disaggregating potentials and risks across them is thus paramount to enable adequate preparation. In the interactive 2-hour workshop, we explored multiple use cases across the rural-urban transect with socio-economic and generational groups at the centre. Design science methodologies were utilised within groups to analyse diverse human-relationships, aiming to contribute to a more disaggregated perspective on autonomous urban mobility futures.

The objective was to collaboratively explore what potential mobility situations might occur for different types of people in a near future with autonomous vehicles in the city of Rouen. The workshop consisted of three parts. First, a pre-recorded video provided the context of the possible future, showing a possible spatial development of Rouen, the underlying assumptions and trends, as well as the elements of the workshop. Second, the participants developed a short story and explored the journey. For this, the participants chose two personas, a trip purpose, a mode of transport, and two types of location as start and destination. The cards were collectively chosen, discussed, and arranged on a virtual collaboration platform (Figure 65).

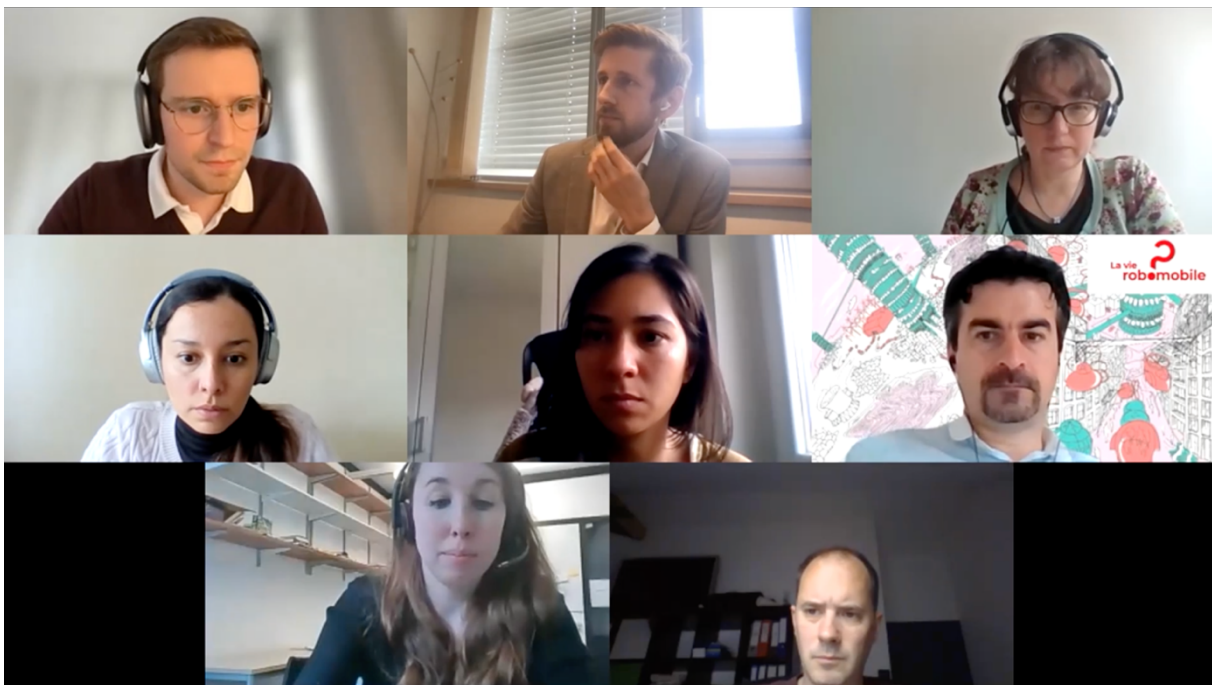


Figure 64: Screenshot of recorded workshop

The participants chose the age group 0-11 years, and the persona 'Elisa': Elisa lives with her father who has to work full time. She visits a kindergarten five days a week. Two afternoons she spends at gymnastics classes. On the weekends and in the holidays, she visits her grandparents in Marseille. As a trip partner, the group '66+

years’ was selected, described as ‘Elderly people, mainly retired, but it is possible that they continue to carry out an activity. These people can be in good or bad health.’ The trip purpose was ‘Professional’ and the mode ‘Public transport.’ The trip origin was defined as ‘Periurban’ and the destination as ‘City Centre.’ Based on the cards, the following story was developed:

‘The AV will travel downtown to transport the passenger, Elisa (and their partner – a neighbour and senior citizen, who is accompanying the child as a visitor) to an audition. The senior citizen is already in the AV when the AV picks the child up. Elisa’s dad scheduled a semi-public shuttle to pick up Elisa to go to her audition. He is busy so has arranged that an old neighbour will accompany her. The neighbour confirms the trip start through his MaaS app a private AV shuttle. He is picked up first. Elisa is notified on her e-watch and supposed to be ready... but actually is not yet, stressed and crying about what to wear. 9 minutes delay to start with... Following a new passenger embarking the transport, there is a lot of noise. Elisa is stressed about her audition. She is finding it difficult to relax as there is a lot of passenger noise which is disrupting her. During the trip there is traffic jam and wrongly parked cars on the street which hinders the automated driving. They consider combining the AV trip with other soft mode of transport (e-scooter, sharing bike to move within the city centre). The pair decide to make the remainder of the journey (~1km) and opt to embark on a small pod-like vehicle which will protect them from the rain and transport them directly to the audition location.’

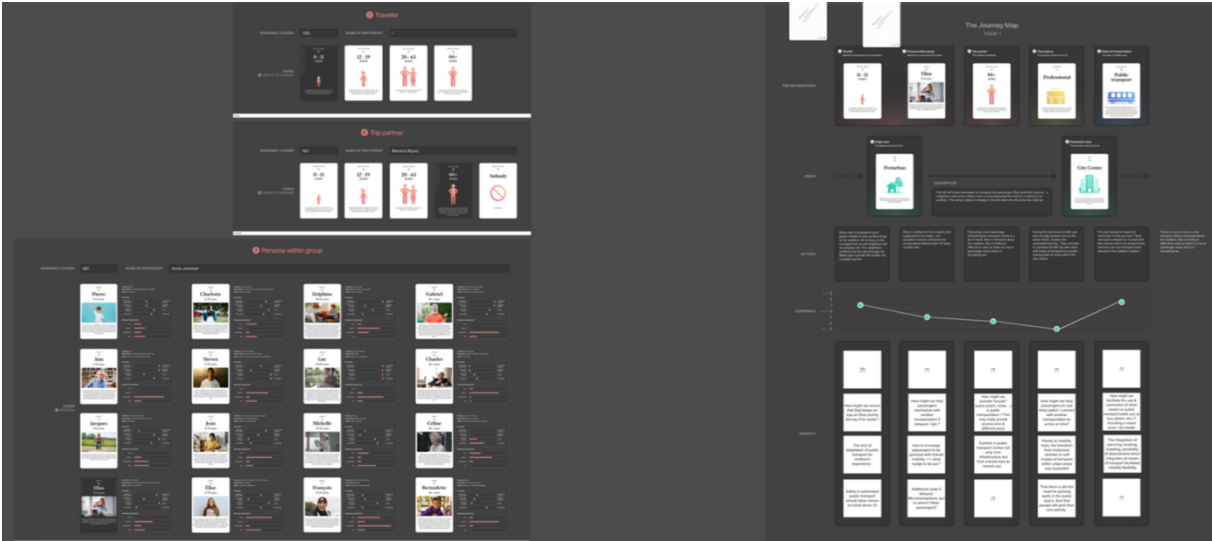


Figure 65: Export of Mural online interaction platform (CC BY 4.0)

Finally, the story was discussed, the quality of the experience rated for the different steps, and insights collected for each of the stages (Figure 66).

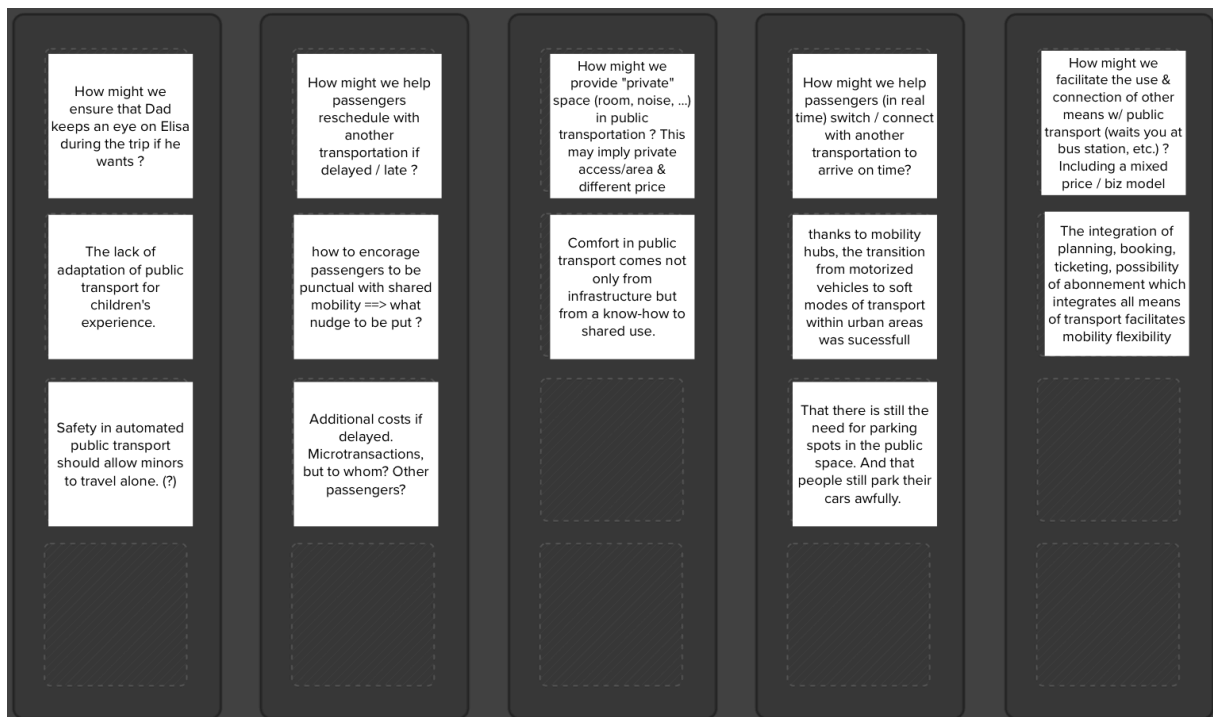


Figure 66: Generated insights for the different steps of the journey (CC BY 4.0)

The workshop has received very positive feedback from the participants and showed the utility of the different used tools; primarily those of personas and a set of choices that create an exploratory situation in a future scenario that allows both to immerse and to imagine specific details that can contribute to the elaboration of new mobility solutions.

Three key insights shaped the following work:

1. While situations may be very specific to AVs, most possible experiences are similar to existing ones. For example, the discomfort created through other passengers.
2. Very detailed, immersive situations can help to identify possible problems of future solutions. For example, how to deal with delayed passengers in shared shuttles.
3. Immersive and exploratory situations within future scenarios can even in a short workshop format stimulate the ideation and in-depth discussion of possible mobility solutions.

AN.3.2: Interviews on partner expectations towards futures studies, Spring 2021

To set the context of the work on urban mobility futures and understand the expectations, we conducted five interviews with the partners of the Chair in spring 2021. Table 33 shows the synthesis thereof. The questions asked were on the usual future time frame, the interest in different global areas, identified challenges within the partner institution's context, as well as ongoing projects that are linked to the futures field.

Table 33: Overview of responses of Chair partners

Partner	Time frame	Geographical interest	Challenges for futures studies	Current projects
[retracted]	~7 years as product cycle Interest: +30 years (2050)	[retracted]	Global scenarios vs local behaviours Weak signals	[retracted] Prospective scenarios 2050
[retracted]	Interest: +5-10 years	[retracted]		Focus on infrastructure/service
[retracted]	Current short to medium Interest: Long term +20, 30 years?	[retracted]	Multimodality AV (logistics, agriculture)	Future society study AV use cases [retracted]
[retracted]	+10 years markets +15 years (infrastructures)	[retracted]	Large scale & dense areas vs town/district & sparsely populated areas Evolution of offers	[retracted]
[retracted]	Current 3-5 years	[retracted]	Preferred futures Backcasting Weak signals	[retracted]

The current timeframes span from 3-5 years (digital projects) to 7-10 years or 15 years for infrastructure projects, whereas there is an interest in projections for product, services, and territorial developments in thirty years, i.e., until 2050. When expressed, the geographical focus is either local for Paris- Saclay or European for [retracted]. [retracted] also targets countries such as the USA, UK, China, or Singapore and envisage more explorations of potentials in fast-paced Asian markets.

Current future-related projects

[retracted]

Collaborations with stakeholders

[retracted]

Challenges: What must be known about the future?

[retracted] points out the need to clarify interrelations between global scenarios and centralised product and service development in combination with very locality-specific user behaviours (for instance what is suitable for Madrid does not necessarily work in Paris).

Both [retracted] and [retracted] insist on the integration of ‘weak signals’ to future visions, which are defined as indicators of a potentially emerging issue that may become significant in the future.

[retracted] envisages the exploration of long-term futures in specific fields such as multimodality. Additional to stimulation through possible futures, exploring different trajectories for public and private actors and their roles in mobility context would be interesting.

[retracted] shows an interest in the clarification of the notion of ‘preferred futures’ and how to use them to feed approaches like backcasting.

For CPS, there are several challenges to handle:

- being able to make projections in a long-term perspective, beyond a political time frame, especially regarding mobility usages which are unknown,
- thinking in terms of *evolution* for mobility offers to enrich and better adapt to the local area,
- jointly designing the *business models* able to accommodate the larger scale of the community as well as the small scale of towns and districts managed by locally elected representatives.

Three key insights of the interviews are:

1. Co-creation of place-based urban mobility futures from the three key actors requires further research – on methodologies, impacts, and potentials.
2. The relation between stakeholders, futures, and place-based urban mobility systems (transition design) appears as key lever to combine futures and strategic action.
3. Multiple possible applications exist across solution and policy design and for different timeframes, between 5 years and several decades.

AN.3.3: Workshop on spatialising urban mobility futures, November 2021

As part of the 57th World Planning Congress: Post-Oil City by the International Society of City and Regional Planners (8-11 November 2021), the special session ‘Envisioning Sustainable Urban Mobility Futures for Doha – A Gamified Co-Creation Workshop’ was organised (Figure 67).



Figure 67: Introduction of global trends

The session with ten participants explored and envisioned multiple possible urban mobility futures through a gamified and interactive workshop. Key themes of the session were to convey central futures studies principles and apply them in a gamified manner to explore possible scenarios of sustainable urban mobility futures in Doha. The workshop was facilitated in cooperation with ISOCARP Institute – Centre for Urban Excellence.

The workshop was framed by the climate crisis that requires immediate system-level transitions in urban areas. Transportation and mobility constitute a significant contributor to current challenges (e.g., GHG emissions, local air pollution, resource/land consumption, traffic fatalities, spatial inaccessibility/injustices; Figure 68). We thus argued that working in a structured approach with multiple exploratory futures can guide designers and policymakers to prepare for upcoming challenges and opportunities. At the same time, normative futures can provide visions, strategic foresight, and action plans through approaches such as backcasting. The field of futures studies can add a powerful layer to planning practice in the quest of enabling systemic sustainability transitions in the urban realm towards more sustainable, resilient, and inclusive urban futures.

At the core of futures studies lies the understanding of the future as a widening possibility space with multiple possible, probable, or preferred futures (Figure 69). Combined with the multilevel perspective and system transition (management) theory, rather philosophical concepts of multiple futures can be translated into actionable insights. A key element, therefore, is the co-creative element, either through workshops, consultations, or validation mechanisms. Useful elements are the gamification of processes to increase the level and depth of participation, the use of

design science approaches such as (future/anti) personas, and future studies-specific methods such as horizon scanning, trend mapping, Delphi method, Causal-Layered Analysis, among other.

ENVISIONING SUSTAINABLE URBAN MOBILITY FUTURES FOR DOHA – GAMIFIED CO-CREATION WORKSHOP

Thursday, 11 November 2021, 11:30-1:00 PM, Room Juman

BACKGROUND

FUTURES

MOTIVATION

CONTEXT

Facilitated by: **AnthroPOLIS** **SystemX** **CentraleSupélec**

In collaboration with: **ISOCARP INSTITUTE** Centre for Urban Excellence

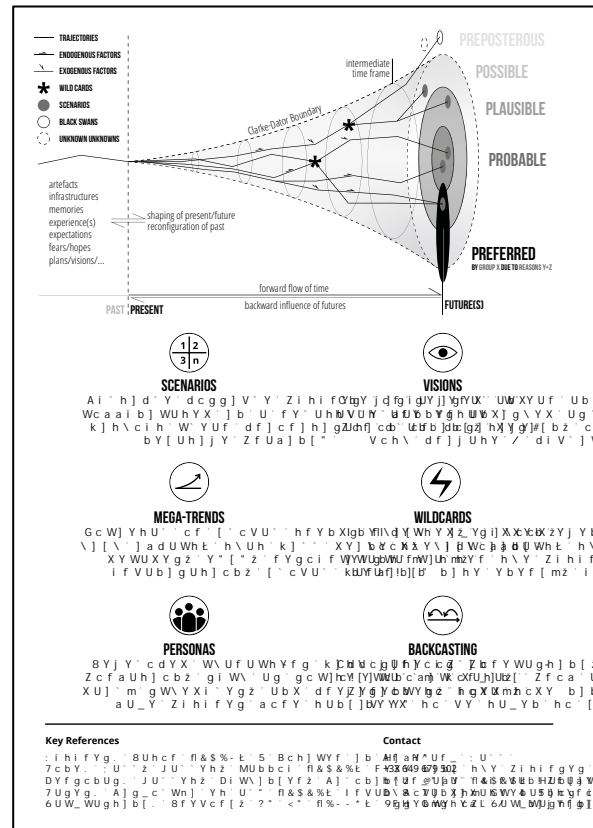


Figure 68: Workshop flyer front (CC BY 4.0)

Figure 69: Workshop flyer back

Building on the conceptual basis described above, the session provided an open innovation environment and testing ground for new approaches to collaborate, plan, and imagine urban futures. For this, the workshop was conducted in three phases:

1. Introductory capacity development, context setting, and process description (10 min)
2. Workshop phase in small groups (50 min)
3. Presentation and discussion of process and outcomes (30 min)

Various materials were created to facilitate the scenario generation and discussion process. A set of personas was developed (Figure 70, Figure 71) to imagine specific stories. Different technology cards (Figure 72) provided input on possible future developments. Three locations, namely a residential area, the city centre, and the new waterfront, were outlined to incorporate the context-specific conditions (Figure 73). Finally, *wild cards* (Figure 74), referring to possible *low-probability, high-impact events*, and a template for strategic backcasting (Figure 75) supported the process.

PERSONAS 1

SUNIL

Sunil runs an online business to promote responsible production. His employees are distributed globally. He was born in Doha and has a service apartment here, but he spends much time in different places. He doesn't have an office. Every day, he goes on bike rides.

Profession: Social entrepreneur
Age: 32
Hobbies: Good food, biking

Personality

Conservative _____ Value-driven _____
 Observing _____ Engaged _____
 Physically passive _____ Active _____
 Introverted _____ Extroverted _____

Motivations

Irrelevant _____ Cost _____ Important _____
 Irrelevant _____ Comfort _____ Important _____
 Irrelevant _____ Sustainability _____ Important _____
 Irrelevant _____ Time _____ Important _____

NOORA

Noora is a digital painter/artist who works with clients to regularly create new colour concepts in offices and commercial spaces. She spends a lot of time travelling between sites. In these times, she tries to connect to friends or prepare her projects.

Profession: Digital painter/artist
Age: 29
Hobbies: Climbing, travelling

Personality

Conservative _____ Value-driven _____
 Observing _____ Engaged _____
 Physically passive _____ Active _____
 Introverted _____ Extroverted _____

Motivations

Irrelevant _____ Cost _____ Important _____
 Irrelevant _____ Comfort _____ Important _____
 Irrelevant _____ Sustainability _____ Important _____
 Irrelevant _____ Time _____ Important _____

Figure 70: Workshop materials, persona sheet 1

PERSONAS 2

STEVEN

Steven moved here for with his parents from Canada. Aside the school classes, he spends most of his weekends and holidays travelling through the region, playing sports, or checking out diving spots along the coast.

Profession: High-school student
Age: 17
Hobbies: Football, diving

Personality

Conservative _____ Value-driven _____
 Observing _____ Engaged _____
 Physically passive _____ Active _____
 Introverted _____ Extroverted _____

Motivations

Irrelevant _____ Cost _____ Important _____
 Irrelevant _____ Comfort _____ Important _____
 Irrelevant _____ Sustainability _____ Important _____
 Irrelevant _____ Time _____ Important _____

Profession: _____
Age: _____
Hobbies: _____

Personality

Conservative _____ Value-driven _____
 Observing _____ Engaged _____
 Physically passive _____ Active _____
 Introverted _____ Extroverted _____


Motivations

Irrelevant _____ Cost _____ Important _____
 Irrelevant _____ Comfort _____ Important _____
 Irrelevant _____ Sustainability _____ Important _____
 Irrelevant _____ Time _____ Important _____

Figure 71: Workshop materials, persona sheet 2


TECHNOLOGIES

SHARED AVS




Shared autonomous vehicles (AVs) include small shuttles, busses, taxis, or even metros. They can be on-demand or following schedules.

PERSONALS AVS



Personal AVs replace the current personal vehicles and the need to drive. This frees time while impacting overall traffic intensity and flow.

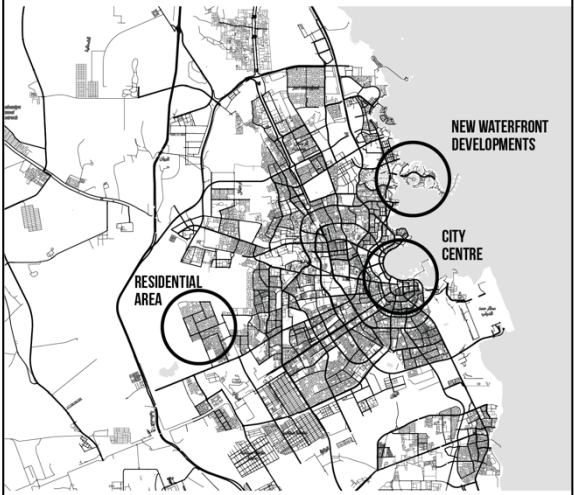
URBAN AIR MOBILITY



UAM refers to the further utilisation of airspace in cities, for taxis, personal mobility, combined with logistics or emergency use cases.

Figure 72: Workshop materials, possible technologies

LOCATION










Figure 73: Workshop materials, details about location

WILDCARDS

2030 END OF OIL	2030 'INFINITE' ENERGY
2025 URBAN EXODUS	2025 AERIAL AV
2030 PERSONAL CAR BAN	2030 FITNESS BOOM
2030 5 MIN CITY	2030 VIRTUAL REALITY
2035 +10° C AVG TEMP.	2035 12H WORKWEEK
2035 -10° C AVG TEMP.	2035 25M POPULATION

Figure 74: Workshop materials, possible wildcards (CC BY 4.0)

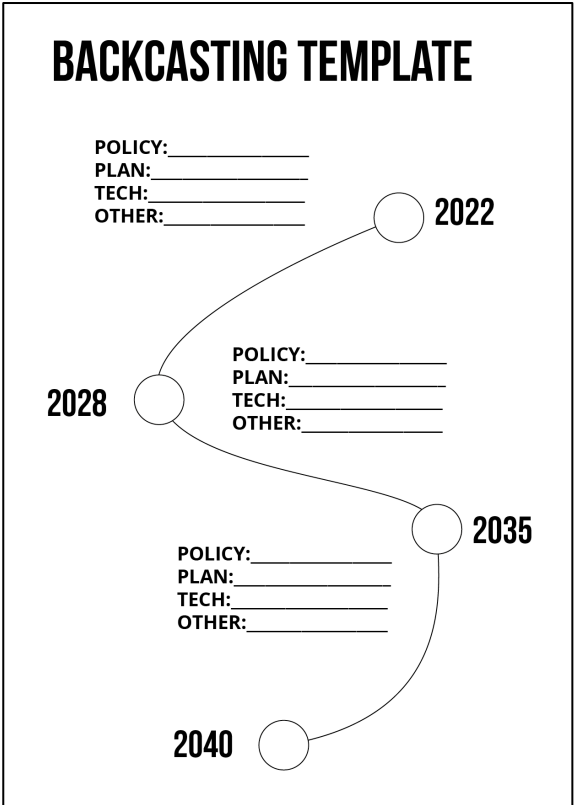


Figure 75: Workshop materials, template for backcasting (CC BY 4.0)

During a guided discussion, the personas, areas, trends, and wild cards were discussed and used to create a spatial mobility scenario of a residential area of Doha 2040. The personas were used to discuss different people’s interaction with the specific area. For example, two of the existing personas (Sunil and Noora) were

considered as residents of the area, while another persona describing a domestic staff member was added to elaborate on their mobility needs and the spatial implications (where do they work, live, move). During the discussion, various challenges were pointed out, such as the high reliance on cars and challenges linked to active mobility in very hot climate. The international and diverse cultural backgrounds led to a very active yet less aligned exchange. Nevertheless, the workshop proved very useful in various ways. First, it showed the usefulness of the materials, in particular the *futures cone, personas, and wildcards*. Secondly, the session aimed to advance on the spatial side of scenarios due to the context of urban planners and designers. While some sketches were made, any attempt to converge on a possible spatial setup was rendered impossible due to strongly diverging design values and models, no distinction between normative and exploratory scenarios, and ‘getting lost in the details.’

Three key learnings from the workshop are:

1. The provided materials (*futures cone, personas, and wildcards*) allowed a quick and effective introduction and work on scenarios with experts with different backgrounds.
2. To make use of the key advantages of futures scenarios, an initial *focus on exploratory instead of normative futures* is necessary to detach the participants from dominating values and seen limitations. In the following, archetypical scenarios as input are used to address this.
3. *Translating uncertain futures into spatial formats is challenging* even when working with planning-domain experts. The need for another method that allows qualitative expert inputs arises.

AN.3.4: Workshop on modelling urban mobility systems, December 2021

An internal workshop with all seven members of the Chair was organised on 7 December 2021. The topic of the workshop was the interdisciplinary modelling of Urban Mobility Systems (UMS). Two of the slides are shown below. Figure 76 shows the different layers that were discussed. Figure 77, on the other hand, proposes a working diagram and vocabulary to work with UMS futures as an intermediary outcome of the workshop.

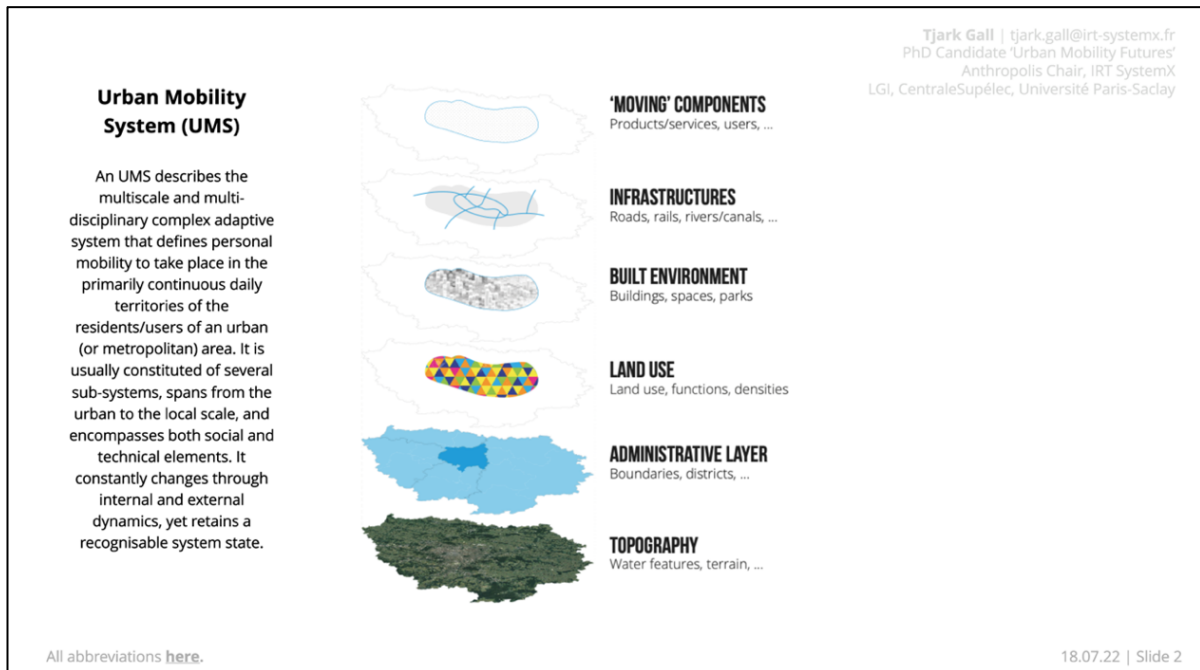


Figure 76: Slide showing different layers of conceptual model of urban mobility systems (CC BY 4.0)

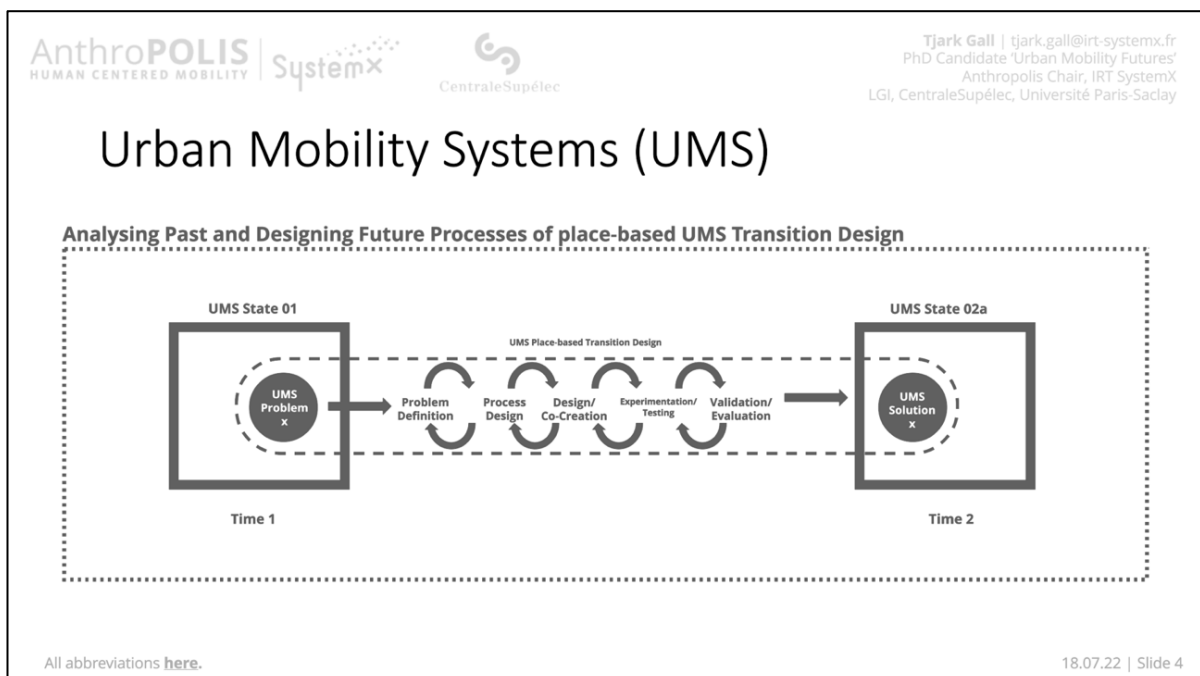


Figure 77: Workshop slide showing the process and interaction between urban mobility states across moments in time (CC BY 4.0)

Three key outputs from the workshop are:

1. UMSs can be seen as sub-systems of urban area (among, e.g., energy, water, housing systems), are multi-layered (e.g., infrastructures, administrative boundaries, topography) with different geographical extents, and various areas to intervene to alter them.
2. UMSs are understood very differently across disciplines. However, the systems approach allows to find a common model. The resulting model is detailed and validated via the subsequently performed expert interviews.
3. Looking at the transition of UMS, we can simplify the process as a state at a certain time where a UMS problem exists, and a later point with a different state, where a solution (that not necessarily eradicates the original problem) exists. The process between these two states is referred to as transition design and the focus of the subsequent work.

AN.3.5: Workshop on assessing future scenarios, March 2022

The following text contains excerpts from the Mémoire Thématique prepared by Malek Ben Ammar under the supervision of Flore Vallet and Tjark Gall at CentraleSupélec (October 2021 to April 2022). The workshop was prepared and conducted by Tjark Gall and Flore Vallet. Malek Ben Ammar attended as an observer.

The workshop, together with the previous set of interviews informs a first version of a *scenario assessment framework for the context of urban mobility*. It builds on the combination of generated insights on the quality assessment, the prioritisation of specific categories in the assessment of urban mobility scenario impacts, and a large range of existing impact assessment methodologies. It therefore acts as a building block for one of the research areas of the Anthropolis Chair that explores methods to design transitions to more sustainable and people-centred futures of urban mobility systems. Two external, three doctoral, and one post-doctoral researcher and two facilitators participated in a 2:15 hour workshop that took place on Friday, 18 March 2022.



Figure 78: Workshop on scenario assessment with the participants 18 March 2022

In the first part, futures studies and scenarios were briefly introduced along with their context of application, and the workshop agenda. Additionally, different sets of scenarios were presented from the mobility context. Four scenario sets, comprising each between two and five scenarios, were selected and used to inform the discussions:

- Carbone4 (C4; Carbone4, 2021)
- Banister Hickman (BH; Banister and Hickmann, 2013)
- Futura Mobility (FM; Futura-Mobility, 2021)
- French Government (FG; CGEDD, 2022)

Each of the scenario sets was presented briefly and handed out in a shortened format for the workshop phase. The participants were grouped in two groups balancing gender and institutions/teams, in which they took one of the following roles:

- Group 1: CPS (Communauté d’Agglomération Paris-Saclay)
- Group 2: Private Sector (Vehicle manufacturer and mobility service provider)

The following step (45 min.) was to explore each organisation that they chose, and the role that they would represent (e.g., R&D, economist). Afterwards, a discussion about the utility of the previously presented scenario sets for each role was initiated. Participants ranked the scenarios sets according to their preferences. This was followed by a brief discussion on the reasons behind their choice process. As a result, the

Table 34 summarises the rankings of each group as well as the justifications provided for their perceptions on the scenario sets and the reasons for their choice.

Table 34: Table showing participant roles, scenario set ranking, and justifications

GROUP	PARTICIPANT ROLES	RANKING	JUSTIFICATION
CPS	#P1: MaaS expert	1: BH	<ul style="list-style-type: none"> • Scenarios that consider criteria that are close to their needs. • Spatial scale adjustable to local setting. • Satisfaction, performance safety in public transport • Consider a temporal perspective in the context of elections
	#P2: External and services	2: FG	
	#P3: Public transport expert	3: C4	
	4: FM		
PRIVATE SECTOR	#P4: Public policy expert	1: C4	
	#P5: Assessment expert	2: BH	
	#P6: Simulation expert	3: FM	
		4: FG	

The second step of 45 minutes was to work on *indicator mapping*. For this step, post-its and whiteboards were used as a support. Participants individually compiled indicators for assessing both the *quality and the impacts of scenarios*, again from the perspective of the assigned role. They were tasked to determine key indicators (quality, social, environmental, economic, and other impacts) and the measures (Qualitative, semi-quantitative, quantitative) that they would use to assess scenarios. Next, the group members presented and discussed their ideas between each other and organised them in a simplified assessment framework. Afterwards, a focus was put on the category of ‘Quality of scenarios’ to detail them further. With this as a basis, the decision of the most adequate set of scenarios from the previous step was

repeated. The outcome was discussed in the group and organised on a whiteboard (described in Table 35).

Table 35: Synthesised outcomes from final discussion

GROUP	CATEGORIES	INDICATORS	
CPS	Political/Governance	Public policy evolution Mobility financing taxation	
	Political/Spatial	Geopolitical aspect	
	Spatial	Vehicle spatial restrictions	
	Spatial/Mobility	Mobility indicators (distance, time to travel)	
	Social	Changes in socio-professional categories Impact on the involved population Quality of life	
	Environmental	Greenhouse Gas Emissions (GHG) Other environmental indicators	
	Technology/Energy	Renewable energy evolution Vehicle technology evolution	
	PRIVATE SECTOR	Quality	Probability/Likelihood of scenarios Concrete and fixed scenario location and horizon
		Quantitative	Demographic forecast: population numbers and socio-demographic attributes Global trends Models/Benchmarks Price evolution: reserves of fossil fuel and evolution of clean renewable energy
		Qualitative	Regulation prospect Technological evolution
Social		Employability Satisfaction of the population	
Spatial		Specific region	
Spatial/Mobility		Mobility indicators (time to travel)	
Environment		GHG emissions Other gas emissions Sound pollution Energy consumption	

In the final part, a series of questions was posed to all participants:

- What are your thoughts on the selection of the most adequate scenario set and more specifically the *appropriate number of scenarios* (neither too little nor too many)?
- What is the optimal balance between the different dimensions (integration of social, economic, other aspects)?
- What issues are missing that were not developed in the scenarios?

The discussion focused on the different advantages and disadvantages of each of the scenarios sets and how (or how not) their characteristics are useful for the two stakeholder groups (public and private). Finally, possible complements or improvements were discussed that would allow the existing scenario sets to better respond to the assumed needs.

Three key outputs from the workshop are:

1. Three elements are crucial for assessing or evaluating scenarios: 1) The *quality assurance* of the scenario, referring to the characteristics they should have, 2) the *assessment of expected impacts* of each scenario across dimensions

- (including social), and 3) the *post-evaluation of the impact* of the use of scenarios on the stakeholders or resulting plans and designs.
2. A set of stakeholder-specific quality assurance criteria can ensure that scenarios are able to fulfil their anticipated role. These include foremost the *combination of usage* of immersive, written, visual, and quantitative *media across dimensions*, the direct discussion of *all parties' stakes* (e.g., the future role of mobility on demand for a company working on mobility solutions), the *similar probabilities* of scenarios, the adapted *local spatial setting* or possible transfer, and the description of the *key events between today and the future* timeframe.
 3. The number of scenarios is crucial. Two scenarios are the minimum but can in most cases not show sufficient diversity. More than seven scenarios are no longer manageable. And uneven number of scenarios easily makes one scenario stand out as the compromise between the others and receives thus more likely interest. An *optimal number* (for exploratory purposes) is thus either *four or six scenarios*.

AN.3.6: Workshop on urban mobility scenarios of CPS, April 2022

The first of two workshops facilitated at the half-day event with the Chair partners on 13 April 2022 at the Laboratoire Génie Industriel, CentraleSupélec, was on 'Scenario simulation of urban mobility system futures,' organised by Tarek Chouaki and Tjark Gall.

The workshop addressed the development of *multi-dimensional scenarios with the goal to inform, among others, multi-agent transport simulation*. It built on the doctoral projects of Tarek Chouaki and Tjark Gall and aimed at compiling partners' inputs for the scenario simulation on larger trends as well as social, technological, and spatial transformations in the context of CPS. Figure 79 below shows the different elements of a scenario development and simulation workflow. The workshop focused on eliciting the Plateau Paris-Saclay-specific inputs for the social, transport, and spatial dimension. These inform the respective resulting scenarios and their synthesis into a set of multidimensional scenarios that can be (1) visualised, (2) assessed, and (3) simulated through agent-based approaches. Finally, the scenarios can inform strategic planning (e.g., areas of densification, a mobility vision), solution design (e.g., supplementary autonomous shuttle services), and policy design (e.g., active mobility incentivisation). The workshop integrated learnings from the Robomobile workshop, notably the use of different inputs and materials to stimulate the scenario immersion, and the localised urban futures workshop in Doha. The latter struggled with the dominance of normative scenarios over exploratory ones, as well as the spatial translation of scenarios. This workshop responded to these challenges through *the use of archetypical scenarios as input*, as well as simplified tools to *qualitatively localise possible future developments*.

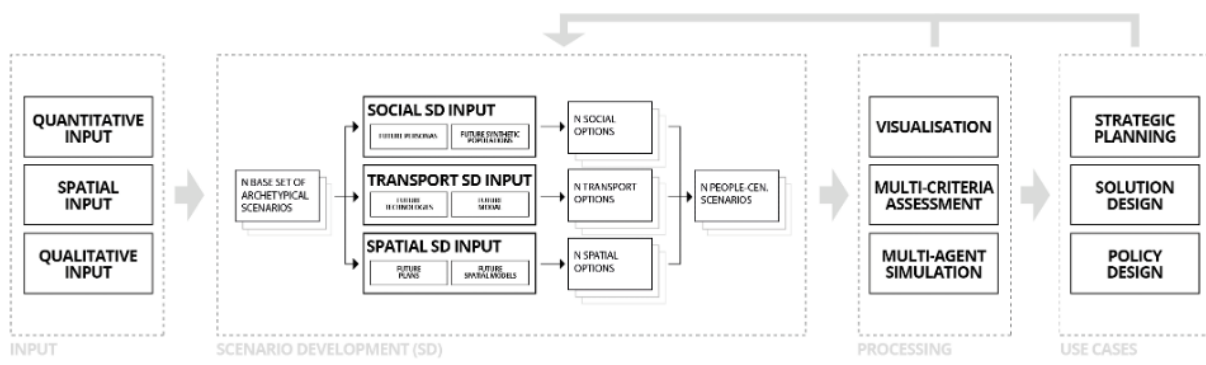


Figure 79: Multi-dimensional archetypical scenario approach (CC BY 4.0)

The workshop focused on the central element of compiling and discussing inputs regarding the social, transport, and spatial dimension. The starting point is a set of scenarios for 2030 that inform each of the subsequent steps. These are building on the scenario archetypes (Fergnani and Jackson, 2019), combined with the most common mobility scenarios for 2030, namely 1) grumpy old transport, 2) slow growth, 3) mine is yours, and 4) tech-eager mobility (Miskolczi et al., 2021). For the workshop, only two, partially combined scenario types were worked on.

Following an introduction and presentation of the overall framework and initial results of agent-based simulations regarding the current state of mobility in the CPS, small working groups for each scenario are formed. These groups set the parameters for input category. For example, in the case of the scenario ‘mine is yours’, personas and their characteristics will be dominated by lifestyles and values that enable a sharing-economy. They are strongly represented in the synthetic population that underlies subsequent agent-based simulations. The transport and technology inputs focus on shared mobility services, and understate vehicle ownership, etc. In the spatial dimension, future developments, densification, and infrastructures are focusing on enabling sharing practices, such as accessible mobility hubs.

Three possible zoom-in areas in CPS are the plateau, the national road RN20, and a rural area. Two working were formed to achieve a diverse composition of background and expertise. One facilitator was assigned to each group. At the end of the working phase, the outcomes from each group were discussed and preferences and probabilities assigned. The collected input will feed the subsequent scenario development, assessment, and simulation. In the following, we describe the workshop materials and the produced outcomes. Afterwards, we discuss the strengths and weaknesses of the applied methodology and cover the feedback collected during and after the session.

Scenarios

Two scenarios were given as an input. Each group worked on one of them. In the beginning, the respective scenario was discussed within the group.

Scenario 1 is called *tech-eager / mine-is-yours*. It builds on the assumption of a steadily growing population, primarily tech-driven development, decreasing individual ownership and increasing servitisation. Furthermore, it expected a fully connected online ecosystem and a high reliance on the mobility offer.

Scenario 2 is referred to as *slow growth / sobriety*, coming with steady population dynamics, a continuation of existing plans, little technological innovation, and considerate environmental individual behaviours. A focus for mobility solutions is on reusing materials and resources and low-tech solutions.

Persona distribution

In the first part of the workshop, six different user profiles (Table 36) were presented. The brief for both groups was to assign profiles according to their occurrence per scenario (Figure 80). The distribution was simplified through a 5*5 grid in which each cell equalled 4% of the anticipated user population of the Saclay Plateau in 2030. We distinguished between two types, namely white background cells for residents (living on the Plateau) and grey for non-residents (working/commuting to the Plateau). The six profiles result from crossing values (conservative vs. progressive) and socio-professional groups (student, worker, retiree).



Figure 80: Distribution of personas by scenario

Table 36: Six persona-like user profiles for distribution and assignment by scenario

ID	NAME	DESCRIPTION
A	Contemporary student	A student with progressive, ecological values and behaviours.
B	Conservative student	A student with conservative, traditional values and behaviours.
C	Contemporary worker	An employee with progressive, ecological values and behaviours.
D	Conservative worker	An employee with conservative, traditional values and behaviours.
E	Contemporary retiree	A retired person with progressive, ecological values and behaviours.
F	Conservative retiree	A retired person with conservative, traditional values and behaviours.

Table 37 and Table 38 show the distribution by the two teams. For the tech-eager scenario, a dominance of contemporary students and workers on the Plateau is anticipated for residents, while contemporary workers and conservative workers define most of the non-resident community. For the slow-growth scenario, the distribution between conservative and contemporary students is equal in the resident community, with a few more contemporary workers. For the non-residents, the

biggest group is assumed to be contemporary workers, followed by conservative workers, and finally an equal number of conservative and contemporary students.

Table 37: Persona distribution for tech-eager scenario
(white: residents/grey: commuters)

A	A	A	B	C
C	C	D	A	A
B	B	C	C	C
C	C	C	C	C
D	D	D	D	F

Table 38: Persona distribution for slow growth
(white: residents/grey: commuters)

A	A	B	B	C
C	C	F	A	A
A	B	B	B	C
C	C	C	C	C
D	D	D	D	D

Spatialisation of scenarios

Following the distribution of personas, the spatial impact of the scenarios and the assumed population constellation was looked at. For this, small supporting cards were provided (Figure 81). Four different types exist. A single arrow refers to an increase of residents, with small (+) to strong (+++) impact. Double arrows refer to an increase of non-residents (outside of the Plateau, e.g., in Massy). The briefcase refers to a strong increase (+++) to a strong decline (---) of employment. Finally, the house shows a decrease (---) or increase (+++) of development in comparison to today's situation. With the help of two maps with different scales – one showing only the Plateau, the other all the Communauté d'Agglomération Paris-Saclay – the cards were distributed across the maps following a discussion between the participants (Figure 82). Figure 83 and Figure 84 show the result for the tech-driven scenario, while Figure 85 and Figure 86 contain the outcome for the slow-growth scenario.

Residents	Residents	Residents	Non-Residents	Non-Residents	Non-Residents
 +++	 ++	 +	 +++	 ++	 +
 +++	 ++	 +	 -	 --	 ---
 +++	 ++	 +	 -	 --	 ---

Figure 81: Cards for decrease/increase of residents and non-residents, new employment, and new developments
(CC BY 4.0)



Figure 82: Location of changes in residential functions and employment



Figure 83: Small-scale spatial scenario for tech-driven developments



Figure 84: Large-scale spatial scenario for tech-driven developments

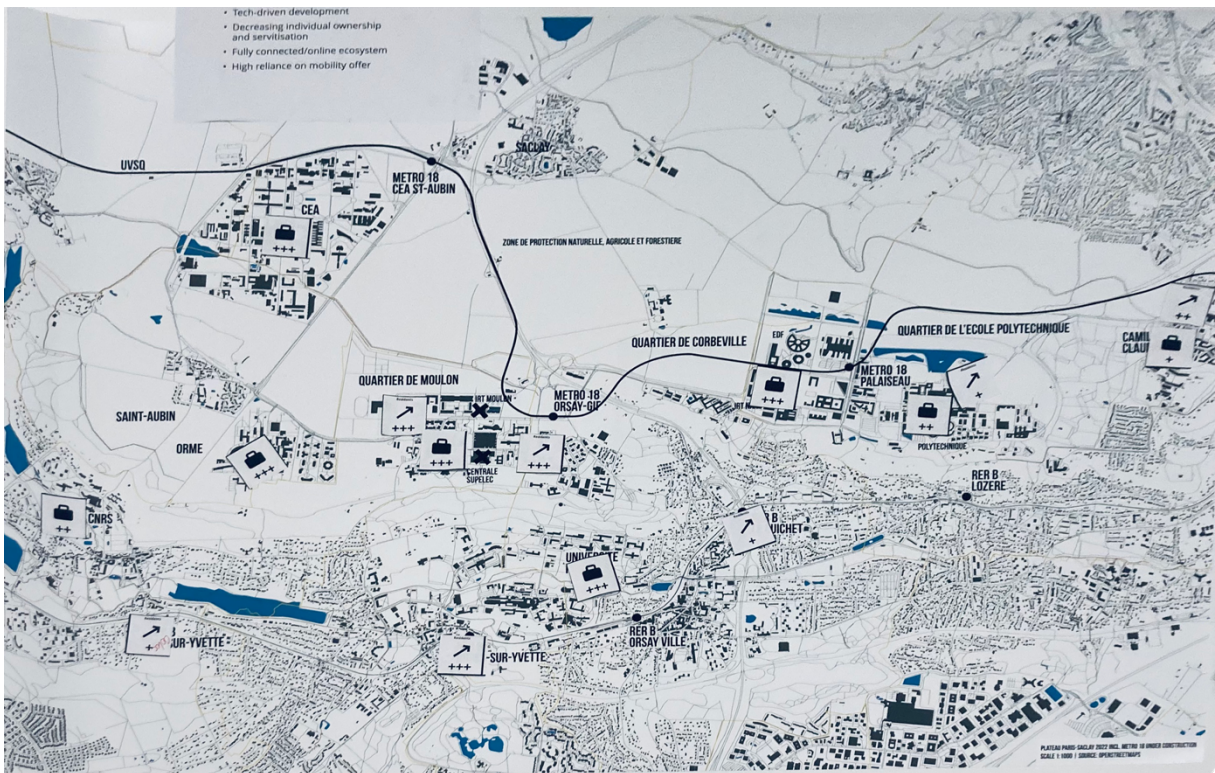


Figure 85: Small-scale spatial scenario for slow growth / sobriety



Figure 86: Large-scale spatial scenario for slow growth / sobriety

Overall, the workshop has fulfilled its objectives. It has applied collaborative workshop elements such as profiles and well as explanatory elements such as the futures cone. Furthermore, the archetypical scenarios provided an easy entry to a complex topic and allowed a sufficient level of exploration without dominance of normative notions. Furthermore, the simplified representation of spatial developments supported the translation of trends and uncertainties into spatialised developments with the help of local knowledge of some participants. For example, the framing of the slow growth scenario led to significantly less newly anticipated development (shown via increasing arrows) in the mapping exercise (compare Figure 83 and Figure 85).

On the contrary, several potentials for improvement were collected. Especially, more time would be needed. The link between the scenarios as framing elements and the spatialisation exercise must be strengthened. More detailed personas instead of the simplified user profiles and immersive materials for the scenarios could support the initial process as well as the alignment with the scenarios. Additionally, a few more underlying information (such as population growth, planned projects) could help the participants to frame their assumptions. Lastly, the materials could be more visual, e.g., via actual persona images and names (multiple for each category to allow for the distribution exercise), while proper cards, monopoly-like houses or pins could enable an easier interaction with the maps. The maps itself could be more detailed and provide more reference information for the participants to orient themselves and quicker grasp the scale.

In the following, different remarks from the participants are addressed. It was suggested to provide more input from the existing territorial diagnosis as an input. While this will be tested in a future workshop, we must be careful to not provide too much information in general, or existing visions or forecasts that lacking accuracy we attempt to address by using exploratory scenarios. Furthermore, the term 'sobriety' requires more definition in the beginning to ensure that everyone has a common understanding. The above-mentioned potential for more detailed personas could assist to understand what the different categories refer to. Three key questions that

remain to be answered are 1) how can we best trigger people to spatially immerse themselves in the future, 2) how can we prime participants for one particular scenario and detach from existing ideas about the future and visions or plans, and 3) how can we make best use of personas to both look at overall distributions and specific stories that can impact the spatial development?

Three key learning from the workshop are:

1. The combination of *user profiles* as simplified version of personas, *archetypical scenarios*, and *development cards* to be positioned on maps allows to work in a short period of time with different experts and elicit their expertise on the social and spatial manifestation of a specific future scenario. User profiles were chosen instead of personas as the individual behaviour was not in the focus. However, the same exercise with more attention to the people could be supported with full personas.
2. An *improved* style and level of detail of the *workshop materials* through colours, shape, and information could strengthen the level of immersion and ease of use.
3. Building on the learnings from the workshop, another one or two workshops could – combined with the results from this one – provide a good *qualitative basis* for the development of *local 2030 scenarios*.

AN.3.7: Workshop on enabling urban transitions, May 2022

As part of the three-week Institut Pascal Research Programme, an in-person focus workshop on urban transitions was organised from 30 May to 3 June with around 10 invited international participants. The workshop is titled ‘A holistic perspective on urban mobility system transitions: Discovering pathways towards people-centred and sustainable mobility of tomorrow’ and was hosted by the Anthropolis Chair. This sub-chapter outlines its motivation, organisation, as well as its outcomes.

The workshop was framed under the challenge that an ever-increasing number of people lives in more and larger urban areas, moving faster, farther, and more frequently than ever before. The urban mobility systems that allow them to get around lead to various social, environmental, and economic challenges, such as pollution, resource scarcity, or inaccessible job markets and basic urban services. How can we design pathways towards urban mobility systems that enable and lead to more sustainable and inclusive urban futures? Answers to this question are building on various theoretical foundations and span fields from urban and transport planning, economics, and governance to behavioural sciences. In some cases, contributions are complementary and allow for interdisciplinary cross-fertilisation. In other cases, concepts or approaches compete. The proposed workshop shall bring different stakeholders together to respond to this challenge, highlight gaps and priorities, and set a pathway for future research and experimentation.

As part of the Institut Pascal Research Programme ‘Urban Mobility II: Healthy, sustainable, and inclusive mobility through the spatial and temporal planning of urban areas, their infrastructure, and their activities’, an in-depth, one-week workshop was planned on the topic of sustainable transitions in the context of urban mobility. We proposed to make use of a *holistic systems perspective* to analyse how today’s urban mobility systems became and can become more sustainable and people-centred. Various theoretical perspectives can be applied to this, such as complex system transitions, multi-level perspective, transition management, evolving social practices, or behavioural science. Exploring and mapping commonalities, differences, and potentials for alignment and integration can contribute to a more systemic and integrated understanding of today’s siloed treatment urban mobility system components and transitions. Such an integrated perspective can build a strong foundation for the design of future services, products, and policies, as well as for recommendations for practitioners and policymakers.

The pre-defined possible research questions were:

- How to analyse/plan transitions across disciplines?
- How to deal with uncertain goals/wicked problems?
- How to deal with opposing stakeholders’ objectives?
- What roles can/do which stakeholders play?
- How to find complementary changes, supporting each other, from different fields?
- How to reconcile/reduce differences/transcend between possible future transitions?
- How to adapt/implement national/global plans and strategies in local transitions?
- What role plays the place? What are the leverage points?
- How to analyse local urban mobility system transitions?

- How to scale up/replicate/mainstream local transitions?

The research programme was organised by Prof Dr Jakob Puchinger, Head of the Anthropolis Chair 'Human-Centred Mobility', Prof Dr Dominique Barth, Director of the DAVID Laboratory, and Prof Dr Eric Monacelli, Professor at the LISV Laboratory and President of CEREMH (Resource and Innovation Centre for Mobility of People with Disabilities). For the international researchers (Figure 87) partaking in the focus workshop, a complementary mix between transport planners/historians, urban planners, engineers, and scientists working on transitions, governance, behavioural changes, and social practices was aimed for. At the core lies the transdisciplinary focus to compile, compare, and harmonise (or contrast).



Figure 87: Group photo of participants⁵⁷

During the first day, we discussed shared interests and different existing transition frameworks. Underlying is a system-of-systems understanding of urban mobility. The overarching motivation was to find ways how can we foster sustainability transitions of urban mobility systems. Specific sub-questions were posed:

- What types of transitions exist? (spatial/tech/behaviour/...)
- What ways to model them?
- What elements can we impact?
- What is most effective?
- Designed transition or design of transition components?
- What data/information is needed? Who produces/owns/uses it...?

To address the questions above, different frameworks were discussed, including the Avoid-Shift-Improve (ASI) framework developed by the German Development Agency (GIZ, 2014), the Multi-Level Perspective (MLP) Approach by Geels, the Social Practice

⁵⁷Left to right: M. Reyes, N. Bonatz, E. Horschutz-Nemoto, T. Gall, F. Vallet, P. Pucci, T. Machiels, I. Jaroudi; not in picture: Michele Tirico, Mir Abolfazl Mostafavi

Theory (SPT), the Complex Adaptive Systems (CAS) and the futures cone as a tool to visualise key concepts of scenario planning.

Based on the framing of the research programme and workshop and the existing works around the topic, shared interests were discussed. These include active mobility, Mobility-as-a-Service (MaaS), planning/designing in uncertainty, mechanisms and triggers for transitions, intermodality, the rural-urban continuum, and modelling spatial structures, among others. During the discussion, the varying use of vocabulary across disciplines became evident, leading to the establishment of a common vocabulary (Table 39).

Table 39: Common vocabulary for workshop

Term	Working definition
Transportation	People as goods
Mobility	According to mobility studies, mobility is more than a travel between A and B. It is a social and spatial phenomenon and includes objects, communication and ideas. It is a prerequisite for social inclusion, it is a 'spatial capital'; it is 'a resource for action' (Coleman, 1990); but also, a heuristic tool to better understanding the uses of urban spaces, to analyse urban rhythms 'the coordinates through which inhabitants and visitors frame and order the urban experience' (Amin and Thrift 2002, p. 17), investigating the time-space variability of urban populations.
Accessibility	Newest term that emphasises the access to services etc. instead of the underlying mobility. Various ways to define, e.g., by spatial connection to services and opportunity, inclusivity of access, affordability
Motility	Concept by Vincent Kaufmann on the potential or capability to move, rather than actual mobility (Kaufmann et al., 2004)
Persona	Archetypical representation of a group of people with specific information (name, age, habits, ...)
Transition	The process of a system or other entity to change from one state to another, either designed/controlled or independently
Transformation	The active alteration of a system or entity. E.g., we transform the public transport system, thus leading to a transition of the overall urban mobility system
Behaviour	Individual perspective on people's actions, in contrast to social practices that are looking rather at group dynamics
Social practices	Larger social dynamics (e.g., changing from car-use to cycling), made up from materials (e.g., bike/infrastructure), skills (e.g., knowing how to cycle), and meanings/values associated to the practice.
Scenario	A possible future used to represent/integrate uncertainty

Approach

At the end of the first day, and building on models, interests, and shared understanding of various mobility concepts, we looked for a specific challenge to address that allows us to work on the defined topics. For this, a shared key interest was identified: *To enable or strengthen active mobility (primarily walking) in semi-urban areas*, in combination with other modes of transport, as well as with a focus on inclusivity for various groups of people. For this, three layers of interrelated transition components were identified: 1) *People*, 2) *Infrastructures*, and 3) *Technologies*.

A first proposition was to apply the social practice theory (SPT) as a guiding framework to analyse the transition of mobility of multiple personas today and in multiple possible scenario contexts. For this, several steps were envisaged:

1. To describe/analyse practices of personas today,
2. To describe possible future scenarios,
3. To explore how practices and scenarios work together,
4. To explore how practices might need to adapt to fit one or several scenarios, considering the overall goal setting,
5. To utilise the social practice components (materials, skills, meanings) to ‘backcast’ and explore potential triggers/nudges/enablers for transitions,

Furthermore, a specific geographical context was chosen: How do different people get to Institut Pascal and the Plateau in general? This context was chosen as it includes the rural-urban characteristics, for many people some kind of intermodality, the possibility for active mobility but with various constraints, and a representative situation for many rather remote work/study locations at the border regions of large metropolitan areas which cannot easily be served by high-quality public transport or are easily accessible by cycling/walking due to a low number of local residences.

An overarching goal was set to leave aside any discussion on normative constraints: The UN Sustainable Development Goals (SDGs) as guiding principles, in particular those related to accessibility, health, and the environment. While most SDGs are relevant in the urban context, we focus on SDG11: Make cities and human settlements inclusive, safe, resilient and sustainable, and the sub-target 11.2. The above culminated in a methodological framework, conceptually visualised in Figure 88. We start at the present moment with different groups of people, represented by personas, and their respective mobility practices. From there, we project to different possible future scenarios in 2040 where we focus again on people, their behaviours and practices. Different, non-linear pathways lead to the scenarios, while the possible practices in the future scenarios feed back into the present, guided by the question ‘What interventions can transform mobility practices?’ The Avoid-Shift-Transform frames the considered interventions, meaning where unsustainable mobility can be avoided, this is the priority, followed by shifting to more sustainable modes (individual motorised transport → public transport → active mobility), and improving the sustainability of remaining modes (e.g., electric vehicles).

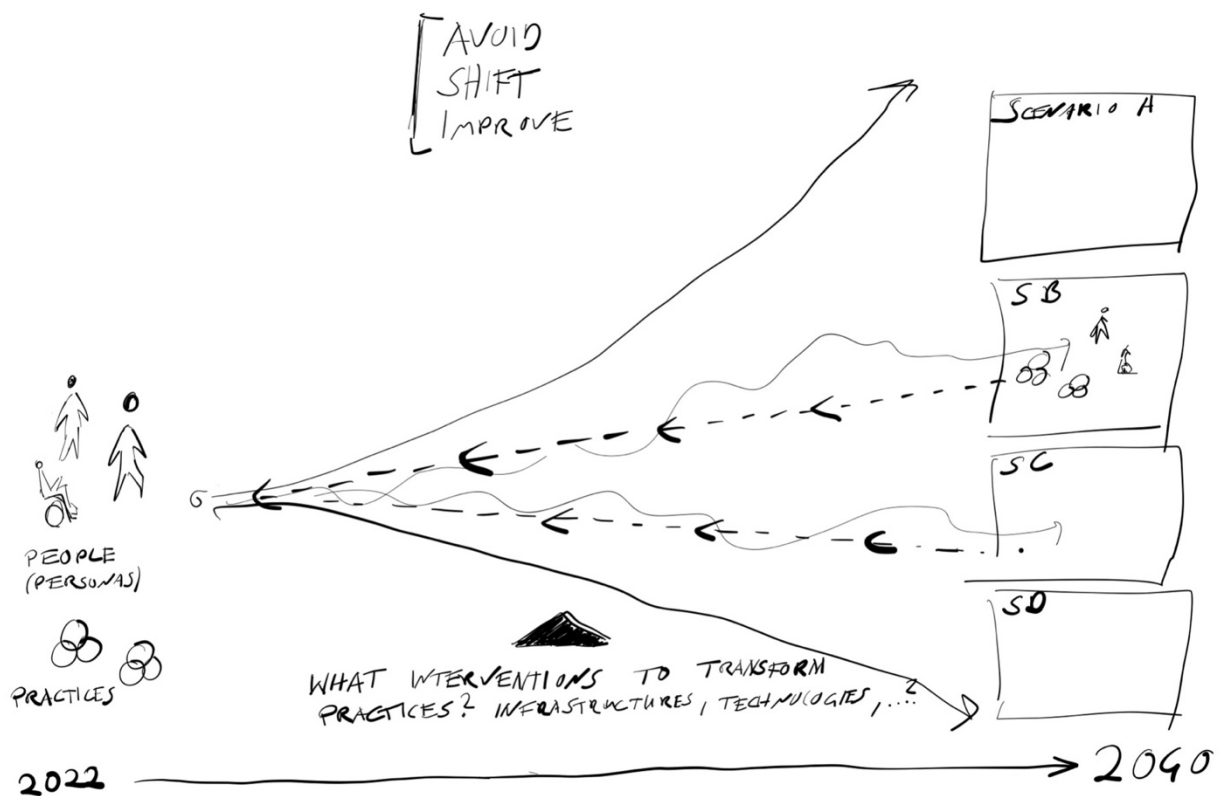


Figure 88: Conceptual sketch of scenarios, with overall all SDG11.2: Sustainable Mobility for All (CC BY 4.0)

The second day was dedicated to an input expert lecture of Professor Paola Pucci from the Politecnico di Milano and the work in smaller groups to prepare personas and scenarios as inputs for the subsequent discussions. The next subchapter outlines the different steps.

Performed steps

The objective was to create a framework that allows to address the transition of mobility practices in a specific context. We chose exemplary the transition to more active mobility in the periurban context of Paris-Saclay. The formulated research question was: *How can we address sustainable mobility transitions towards post-car/active mobility on developing territories in conditions of uncertainty?* The continuation of this work has been presented in Chapter 5.1.3.2. Open questions of interest at the end of the workshop were:

- Should we choose one scenario or work with several scenarios? What are the advantages/ disadvantages of both?
- What is the role of plans in scenario-making?
- How to conduct/foster the storytelling? KPIs: Creative, realistic...
- Subjective process vs. objective process? How to make the process more grounded?
- Can we account for the designer's bias regarding the social profile of personas?
- What are the parameters that should be fixed or variable for scenario and persona building? How to manage the multiple heterogeneous variables to reduce complexity: In what order?
- Is it useful to throw wild cards in the process? When?
- How to integrate SDGs to scenario and persona development?

Three key outputs from the workshop are:

1. Scenarios and personas provide a powerful tool to *identify intervention priorities*.
2. The creation of several possible exploratory scenarios allows to *test strategies and interventions* and *'futureproof'* them while trying to identify no and low regret strategies.
3. The urban mobility system is a complex and intertwined system of many elements. To work with it, we need to reduce its complexity and – in some cases – define a *clear order* what changes as an input or as a consequence of what. We proposed and tested the order of *people* → *space* → *mobility service* which appears most coherent.

AN.3.8: Interviews of urban mobility experts, Spring 2022

As introduced, 16 semi-structured expert interviews were conducted in the first half of 2022. The given context of the interviews was set as the challenge that more people live in more and larger urban areas, moving faster, farther, and more frequently than ever before. The urban mobility systems that serve them lead to various social, environmental, and economic challenges, such as pollution, resource scarcity, or inaccessible job markets and basic urban services. Fast, integrated, multi-scale, and system-wide responses are needed to address these challenges.

The interviews were aiming to inform the search for ways how today's urban mobility systems can become more sustainable and people-centred. Their inputs should support the development of the expected outcomes. These are (1) a holistic model of urban mobility, (2) an analysis approach for urban mobility system transition, and (3) a transition design process. More in detail, the objective of the interviews was to collect insights that allow us to model urban mobility systems and their transitions more accurately, integrating insights from various fields of expertise and application.

The following is a work-in-progress description as the analysis of the interviews is still ongoing. The underlying interview guideline and privacy protocol are accessible in Annex 1-2. Two of the 16 interviews were not transcribed fully due to technical problems and one participant's preference. They are nevertheless fully considered in the qualitative analysis.

In the following section, we provide a short overview of some of the key findings from the interviews. We start with an aggregated response to each of the question sub-groups across periods from the interview guideline. This is followed by set of remarks and findings that arose during the discussions but are not directly related to the

What are the key components of an urban mobility system?

The key part of the interviews resolved around the identification of critical components of urban mobility systems. These include, for example, physical and non-physical infrastructures, as well as actors. As the majority of the interviewees were either based in greater Paris and/or working on the same geographical scale, the following compilations include the greater Parisian equivalents, e.g., RATP or IDFM as public transport authorities, even if the international respondents might have mentioned their local equivalents thereof.

The discussion of the urban mobility system has mostly taken place in two steps. First, infrastructures, users, various services, or policies were mentioned. In the following, we structure this in three layers, as phrased by one of the respondents: ‘les modes de déplacement, les infrastructures et les gens qui les utilisent’, or the mobility modes/services, the infrastructures (including built environment, land use, ...), and the people as user (or those impacted by the system). As expanded on in the findings outside the framework, the interviewees started their discussions mostly within their field and expanded afterwards to include primarily coherent responses between disciplines. Thus, we do not distinguish between the components mentioned by different disciplines as long as it has not been mentioned only by one particular discipline or stuck out otherwise. All system components mentioned by at least two interviewees are, organised by the three layers, are shown in Table 40.

Table 40: Compilation of urban mobility system components

	ID	Components
People	P1	Mobility user (with different capabilities, preferences, practices)
	P2	People excluded/discriminated by mobility system (e.g., due to gender, disabilities, location)
	P3	People affected negatively by mobility system (e.g., through pollution, resettlement, gentrification)
	P4	People working in the mobility sector (e.g., drivers, conductors, security)
	P5	People working in sectors dependant on mobility (e.g., OEM, part suppliers, infrastructure providers)
Services	S1	Public transport (incl. trains, metro, tram, busses, BRT/LRT, shuttles)
	S2	Free-floating bike sharing (e.g., Dott, Uber)
	S3	Fixed-station bike sharing (e.g., Velib)
	S4	Free-floating micromobility sharing (e.g., Dott, Lime)
	S5	Long-term bike rental (Veligo, Swapfiets)
	S6	Short-term bike rental (e.g., Holland Bikes, Velib day passes)
	S7	Bike sharing
	S8	Mobility on demand / ride-hailing services (e.g., G7, Uber, Bolt)
	S9	Ride-sharing services (usually paid passenger on existing trips, e.g., BlaBlaCar)
	S10	Ride-pooling services (moving various people with different trips together, e.g. Uber Pool)
	S11	Car-pooling (e.g., colleagues rotating who drives to work)
	S12	Commercial car-sharing (e.g., FreeNow)
	S13	Peer-to-peer car-sharing (e.g., Getaround)
	S14	Car-rental (e.g., Europcar, Hertz, Avis)
	S15	Shared or individual industry or institution employee shuttle busses (e.g., Zenbus Navette)
	S16	Charing services/stations (e.g., Belib)
	S17	Navigation or MaaS apps (e.g., RATP Bonjour, IDFM, CityMapper)

	ID	Components
Infrastructures	I1	Roads, pathways, sidewalks, ...
	I2	Rails, tramways, ...
	I3	Built environment (e.g., buildings, houses, incl. its density, urban form, etc.)
	I4	Public spaces (e.g., squares)
	I5	Parking spots
	I6	Natural infrastructures (e.g., rivers)
	I7	Land use / functions
	I8	Electricity/power/charging infrastructure
	I9	Public transport infrastructure (e.g., bus stops, stations)
	I10	Urban furniture (e.g., benches that allow to wait for transport)
	I11	Signage, signaling, traffic light
	I12	Digital/virtual infrastructures, incl. data sensors, interfaces

Following the compilation and discussion of system components, the interviewees responded to the key actors of the urban mobility system. These are structured with the help of the quadruple helix framework (Carayannis and Campbell, 2009) with its four stakeholder categories of academia (A), civil society (C), government (G), and industry (I) and shown below in Table 41. The actors are ranked qualitative by their dominance in the interviewees' responses.

Table 41: Compilation of urban mobility system actors, their Parisian equivalent, and their characteristics

Actor	Example(s)	A	C	G	I
Public transport authority	Île-de-France Mobilités (IDFM)			X	(X)
Public transport operator	RATP, SNCF, ...			(X)	X
Infrastructure provider	SNCF Réseau				
Mobility users	Residents, tourists, ...		X		
Local governments	Saclay, Paris, Gif-sur-Yvette			X	
Inter-council governments	Communauté d'Agglomération Paris-Saclay, Métropole du Grand Paris			X	
Regional governments	Essonne, Île-de-France			X	
National governments	France			X	
Inter-governmental agencies	EU, EC, OECD			X	
International organisation	UITP	(X)	(X)	(X)	
Research institutions	CEREMA, LVMT	X			
Electricity utility provider	EDF			(X)	(X)
Car producers/OEMs	Groupe Renault				X
Software/Technology providers	Nokia Bell Labs, Engie				X
Planning agencies	Institut Paris Region	(X)		X	
Planning offices		(X)			(X)
Mobility service provider	Dott, Uber, Bolt				X
Interest groups	Paris en Selle, Collectif Contre la Ligne 18		X		(X)

On the specific question if the interviewees consider the set up and components of urban mobility systems the same or different in varying locations, all responded that while differences of course exist (e.g., having a metro or not, the mobility governance model) the key structure and function is similar across locations.

Finally, not too many detailed responses were provided on the development of the components over time. Frequent examples included the appearance and disappearance of impactful mobility services (such as Velib or Autolib), the impacts of changing responsibilities in the governance ecosystem (such as the regional mobility authorities), as well as the complexification of the stakeholder ecosystem, mostly on the industry side, the increased collaboration between private and public sector, and the increasing focus on sustainable and healthy, active mobility.

The geographical extent of an urban mobility system

One of the most challenging questions for the interviewees, as well as the one with the most diverse responses across disciplines and individuals was that on a method or approach to define the geographical system boundaries of an urban mobility system. Most answers started with some kind of base system, for example the public transportation system, or the primarily continuous built-up environment. Afterwards, the more detailed responses spanned the administrative boundaries (either due to political regulation or data availability), indicators combining built-up and population density, the accessibility to other districts within the same urban area, the number of passenger kilometres per network fraction, or the commuting relationships. A consensus between the responses can be found in the proposition of a multi-level model with one or multiple core inner-city urban mobility system, a peri-urban system, outer rural systems, partial overlaps between systems of different centres (e.g., of Paris and Versailles), and a mix of spatial, functional, administrative, and flow-relationship indicators that define the levels thereof.

Purpose

The question of the primary purpose of the urban mobility system – and its possible way to measure the fulfilment thereof – has been asked to all interviewees, in most cases across the three different timescales. The idea behind the set of questions was to understand what the urban mobility system is supposed to do across disciplines to perform well, as well as to understand better if there are developments over time. First, the most common answer was about the effective (time, reliability), affordable (cost), comfortable, and sometimes sustainable (emissions, resources consumption) to move people between the different locations where they must be. In some cases, the need to keep a restricted offer was mentioned at the same time, primarily from the economist perspectives, to avoid an over-consumption of mobility, or in other words, an induced demand. In a second level, the need to move resources throughout the productive urban areas has been referred to by some of the interviewees. In this case, while strongly linked to the first point, the focus lies on the urban system functioning (see, e.g., agglomeration economies) primarily instead of the individuals that move through the city. Lastly, references were made to the quality of life of urban residents and users in general. In this regard, concepts such as the urban villages, 15-minute cities, the ‘exodus’ to medium-sized cities, or the benefits of remote-work were mentioned as ways to decrease the time spent in traffic or transport and as a way to build more local and functioning areas. The latter has been mostly discussed by interviewees in the urban domain, while the transportation and mobility experts were more focused on the increase of efficiency, comfort, or sustainability through new

infrastructures, technologies or improved management thereof. In general, mobility has predominantly been seen as an induced need.⁵⁸ A topic appearing only at the side-lines of the exchanges was the purpose of mobility as a need in itself, meaning the need to move for the primary sake of moving. References to this were made in the context of the pandemic where some people did not have other reasons to move and thus looked for new ways to move locally, as well as the trend of increasing active mobility. In case of the latter, the focus is less on mobility as an inherent or induced need only but a mutually beneficial combination of both. We can summarise the exchanges around the purpose of urban mobility systems by primarily focusing on efficiency, accessibility, affordability, comfort (increasing importance over time), the need for certain in-built system limits to avoid widespread hyper-mobility while favouring local and active mobility, and support of types of mobility that create co-benefits, such as active mobility.

Sustainability and people-centredness

Short discussions were held on the level of sustainability and people-centredness of past, present and possible future urban mobility systems. Overall, a consensus existed that the past systems were not sustainable, that the present systems are more sustainable and consider people more but still have significant problems. For the future systems, some visionary statements were made, however, significant challenges to truly sustainable and people-centred urban mobility systems were mentioned for several reasons. First, one concern was the overall ongoing technology and digitalisation-driven increase of passenger kilometres per capita as well as increase of maximum speeds across modes and its higher energy demands. Further, the strong and increasing number and power of private stakeholders in the mobility ecosystem, as well as its overall complexification, created doubts on the ability to manage and regulate the system as it would be needed to prioritise, for example, environmental goals. Despite recent advances, this challenge is seen across the past, present, and possible future systems. Hope was expressed due to the improving consideration of inclusive solutions, recent trends to active mobility, and strong regulatory movements across Europe and France in particular.

Other findings outside the initial framework

During the interviews, particularly three larger elements became apparent. First, most experts working on mobility share a dual, sometimes dichotomous, position as a consequence and mix between personal experience as mobility user and professional. To provide a few examples, the answers at one moment are focused on the primary field of research, e.g., road or charging infrastructures or autonomous vehicles. In a later part of the answer to the same question, or for the following one, a shift of perspective to the personal perspective as user commuting to work by public transport has occurred several times. While this is a natural bias when working in a field that concerns everyone in one way or the other, it is important to keep it in mind in collaborative activities or during data collection and attempt to separate professional insights from personal preferences or perceptions (even if both might be aligned and influencing each other).

Secondly, there appears a strong variance between the starting point when we talk about urban mobility. For some, it was people, for others technology, the network of

⁵⁸ A need that results from another need. For example, the need to be at work or to buy something.

roads, charging systems, public transport reach, or the reach of policy via administrative boundaries. Despite this broad range of initial reaction, in most cases the following responses converge over time and cover very similar topics across disciplines.

Finally, while interviewing very different profiles, a sufficiently strong overlap existing between all interviewees without exceptions. This allows to assume that the core structure of a holistic model of urban mobility systems that can respond to the needs of different fields and simultaneously allow for the collaborative discussion thereof is possible. Afterwards, it can be fed by more detailed insights from different fields that go in a higher level of detail in, for example, the spatial specificities of the built environment, or the layers of digital systems for transport modelling or simulation.

Key insights of the expert interviews are:

1. *Urban mobility systems* can be modelled across disciplines with components across three dimensions – *people*, *mobility services*, and *infrastructures*, thus, allowing to collaborate across fields of mobility design, planning, or policymaking and provide the *foundation for transition design* in the context of *uncertain futures*.
2. While certain future trends of mobility system developments are seen across disciplines, in general, there seems to be *no consensus*, or oftentimes only speculative ideas of *how the future* of urban mobility *might look like*. On the other hand, *normative* or *visionary perspectives* are widespread – yet mostly *paired with* rather *pessimistic outlooks*. Thus, the planning and design of urban mobility systems *integrating uncertainty* seems a *crucial component to prepare for the unknown future*.
3. The question of locality, geographical context, extent, and place-based solutions received interest and consideration across disciplines, yet without clear solutions how to address the associated challenges. The definition of a possibly *multi-layered and multi-dimensional extent of urban mobility systems* could constitute a promising avenue for *further research*.

AN.3.9: Expert scenario-localisation workshop in Cairo

In late October 2022, an expert workshop was organised in collaboration with the AUC. About 30 people were invited via existing contacts and the networks of the local partners, combining urban design, urban planning, and mobility/transport experts. About 25 confirmed their participation and 14 people were present. The participation rate was lower than expected due to an extreme rainfall leading to significant infrastructure flooding and gridlock on major arteries. The workshop consisted of four parts. First, key ideas, concepts, and motivation was presented in an introductory presentation, as well as the opportunity to ask questions. Next, the concepts of trends and uncertainties was presented to localise scenarios and an interactive quiz was conducted to test if the distinction between the two was conveyed and how participants react to, for example, urbanisation being a trend or uncertainty. Foremost, the reaction was as anticipated, and the two terms permitted to quickly enter the discussion on what we can assume as given and what are the important

elements that might change. Secondly, overall homogenous responses were given during the quiz, with some terms evoking interesting discussions how likely they are. In the third part, two groups worked with the support of maps with the task to spatially localise 2030 scenarios in an inner Cairo section. One group was given a map that had as first task the listing of key uncertainties before collectively imagining how it could manifest in the urban environment. The other group had workshop materials with the reverse order (Figure 89).

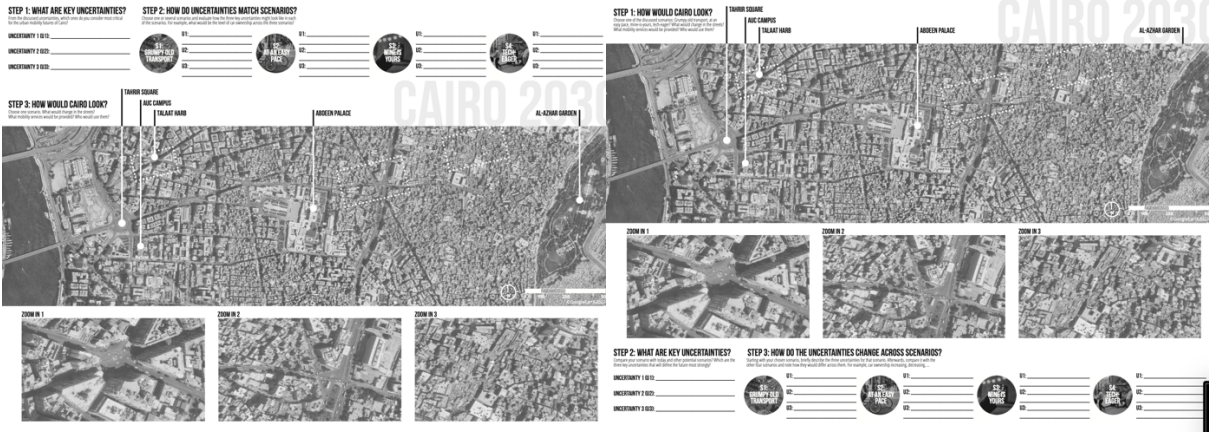


Figure 89: Two versions of materials for Cairo scenario localisation workshop

While some similar challenges were faced as during the Doha workshop, for example, the challenge to separate between normative and exploratory notions, the more structured and spatial approach, as well as the mix between urban planners and mobility experts, permitted for both groups to create local versions of future scenarios. As observed during the workshop, as well as mentioned in the subsequent discussion, an iterative mode of the second version was perceived as most suitable. This means starting in the spatial context, noting down key uncertainties and their variations for the pre-defined scenarios (e.g., archetypical ones), and continuing with the spatial process. Without being able to clearly delineate each iteration, relatively quick iterations towards the end of the working period (about 45 minutes) led to approximately a dozen iterations. In the fourth and last part of the workshop, a longer discussion was conducted, initiated by the presentation of both groups' work, their challenges, and findings. While the localisation and translation into uncertainties was perceived challenging – as expected – a very positive feedback was provided regarding the relevance of futures, the utility of the cone as visual artifact, and the trends/uncertainties-based approach.

Key insights of the workshop are:

1. Trends and uncertainties are useful simplifications and terms of stable and changing components of future scenarios that permit rapid expert knowledge activation.
2. The localisation approach using uncertainties concurrently to a geographical canvas permits to localise possible future development, inform uncertainties, and appears to work best in an iterative manner, starting with the spatial lens.
3. All used materials, including the futures cone, were perceived as helpful intermediary design objects. Furthermore, an overall high interest and positive

feedback regarding perceived *necessity and utility of foresight* confirmed the relevance of the work in heterogenous environments.

AN.3.10: Chair workshop on scenario simulations in June 2023

An internal workshop with people of the immediate network of the Anthropolis Chair was organised in June 2023. The workshop was intended by eleven people of which four are part of the core of the Chair. The goal was the presentation, discussion, and validation of the scenario simulations work. Following an initial conceptual and technical presentation of the work, a first discussion permitted to delve deeper into the approach, its potentials, and limitations. For the first part, an additional four people participated online. The second part focused on the results as presented in Chapter 5.1.3.1 and Annex AN.6.4. A large part was dedicated to clarification questions, mostly regarding underlying assumptions and technical capacities. Another discussion focused on which simulation and modelling approach serves which purpose and when agent-based simulations bear most potentials. The validity of the results was confirmed by the participants. Most interestingly, the subsequent discussion focused on further application cases and potentials. These are perceived as key insights from the workshop and listed as point two and three in the following box.



Key insights of the workshop are:

1. The scenario simulation results are perceived as *realistic, useful, and validated*.
2. The approach is perceived as useful and many other application cases can be imagined, including different scenarios, the comparison of multiple solutions, higher-detailer simulations of specific areas.
3. Various technological or methodological extensions were discussed. These include the previously mentioned and ongoing exploration of *different choice models of personas*, the integration of *factors such as comfort* in the utility

function, *more options*, *simplified models* integrating values resulting from more complex agent-based simulations for rapid assessments and sensitivity testing, and expanded approaches for simulation result validation as well as model calibration.

AN.3.11: Validation workshops for decision support tool

The last co-creative part was organised in July and consisted of a set of individual experiments, two in-person workshops with five participants respectively, as well as supplementary unsupervised online validation. Participants were purposively sampled from a heterogeneous group of researchers in urban, mobility, and design disciplines. Each activity served the calibration and validation of the decision support tool presented in Chapter 5.1.3.2. Following the initial expert workshop in May 2022 (see AN.3.7), a prototype of the online interface was created. In the first validation step, the focus lied on individual tests of the interface with people of the immediate environment as well as two of the original workshop participants. Next, a first in-person group workshop was organised. The workshop consisted of a short introduction presentation as well as a walk-through of the tool. This was followed by two tasks: 1) Adding a predefined scenario to the tool, and 2) Adding a second mobility solution and rapidly assess its impact. The workshop was scheduled to take place for one hour and took slightly longer. An ex-ante and ex-post online questionnaire asked questions regarding initial knowledge, perceived impact of the tool use, overall feedback, and potential fields of application. The outcomes thereof are described in the main text (cf. Chapter 5.1.3.2.). While a number of useful comments and proposals were collected for the tool, a number of challenges prevailed. The most dominant ones were the complexity of the interface and the wish for an optional simplified interface, the difficulty to execute the two tasks during the short period (imposed by the need to find a time where everyone is available), and the attempt to test too many things at once. Thus, the second workshop was significantly streamlined, as well as first simplifications of the interface implemented. The core change of the workshop was that the participants were partaking in a role play as task team of a local authority which receives a representative of a fictive mobility company that proposes a SAEV service. After a short pitch of the company, one person was using the tool which was displayed on a large screen. The second workshop was much more successful and showed effectively that the tool can permit a rapid assessment, integrate scenarios and a people-centred perspective via the personas, as well as effectively stimulating the exchange of the heterogeneous group of participants. Additionally, a number of technical and user interface-related comments were collected. Finally, a few online experiments followed for those who could not participate in person. More extended discussions of the conceptual findings are included in Chapter 5.1.3.2. All workshop materials and feedbacks are available on request.

Key insights of the workshop are:

1. While the goal was to avoid a ‘black box’ approach, not all information and options for modifications should be always visible. *A balance between simple and complex* is necessary to respond to diverse needs. Mobility experts prefer

detailed input fields while end users prefer simple and quick decision support processes. Initial implementations via *possibilities to hide parts appear promising*.

2. A significant difference was found between disciplines. Economists want information about utility and financial resources of personas while others want more information on mobility modes. The tool managed to *facilitate the exchange* but has *further potential to provide detailed, discipline-specific information*.
3. Despite some technical and procedural challenges, the approach and related interface received *consistently positive feedback* and seem – after further development – to be a promising tool to support design and decision-making while integrating future uncertainties via scenarios and heterogenous people characteristics and needs via personas.

AN.4: Urban mobility policies and plans

Table 42: Multi-level policies impacting urban mobility planning and design in Paris-Saclay

Document Name	Author	Year	Timeframe	Difference	Scale
Agenda 21	UN	1992	2005	13	International
Kyoto Protocol	UN	1997	2012	15	International
Commission on Sustainable Development	UN	2001	2020	19	International
Schéma de Développement Territorial	EPAPS	2012	2025	13	Local
Kyoto Protocol, Doha Amendment	UN	2012	2020	8	International
Plan de déplacements urbains d'Île-de-France		2014	2020	6	Regional
UN Sustainable Development Goals	UN	2015	2030	15	International
Paris Agreement	UN	2015	2050	35	International
EU NDC 1	EC	2016	2050	34	International
Comité d'évaluation de l'amélioration de l'offre de transport en Île-de-France 2016		2016	2025	9	Regional
Projet de Territoire: 2016-2026	CPS	2016	2026	10	Local
Plan Climat	Min Ecologie	2017	2050	33	National
New Urban Agenda	UN	2017	2030	13	International
EU Mobility Packages	European Commission	2017	2030	13	International
Comité d'évaluation de l'amélioration de l'offre de		2017	2022	5	Regional

Document Name	Author	Year	Timeframe	Difference	Scale
transport en Île-de-France 2017					
Schéma cadre des Mobilités: 2017-2021	Essonne	2017	2028	11	Local
Concertation préalable à l'aménagement de la ZAC de Corbeville	EPAPS	2018	2024	6	Local
Le nouveau pacte ferroviaire	Ministère de la Transition Écologique et Solidaire	2018	2039	21	National
Le Plan Vélo départemental	Essonne	2018	2021	3	Local
Comite d'évaluation de l'amélioration de l'offre de transport en Île-de-France: Rapport pour l'année 2018	IDFM	2018	2030	12	Regional
Plan Vélo & Mobilités Actives		2018	2024	6	National
Schéma de Transports 2018- 2026	CPS	2019	2030	11	Local
Plan Climat Air Énergie Territorial 2019-2024		2019	2100	81	Local
Schéma Directeur des Circulations Douces	CPS	2019	2022	3	Local
EU NDC 2	EC	2020	2050	30	National
Révision du Plan Local d'Urbanisme	Orsay	2020	2030	10	Local
Loi Mobilités		2020	2050	30	National

AN.5: Urban mobility solutions database

This database (Figure 90) has been created at the start of the doctoral project to gain insights in the various types of possible interventions in the urban mobility system. They have supported the process throughout by reminding us on what various perspectives and disciplines should be considered in a holistic approach as well as informing participatory exercises such as the online tool development. At the time of writing, an interactive online version of the database with complementary information is available online here:

<https://urban-mobility-futures.notion.site/3b4cb3e4fccd48a38cda6149a0d6ffa1?v=8ce1115a24e7436f8c31bdd58a3c74ef&pvs=4>

Urban Mobility Solution Database

This page shows a non-comprehensive list of possible types of Urban Mobility Solutions. Some are based on existing compilations [1, 2, 3, 4]. Cf. [Wiki La Fabrique des Mobilites](#)

↓ Click **Gallery** below to switch to list view or organise by **Goal** according to AST Framework (Avoid, Shift, Transform), **Type** (Policy, Action, Product, Service, Product-Service-System), or **Scale** (Micro, Meso, Macro).

The screenshot shows the 'Urban Mobility Solution Database' interface. At the top, there are navigation options: 'Gallery' (selected), 'List', and filters for 'Goal' (Avoid, Shift, Improve) and '8 more...'. There are also 'Filter', 'Sort', and 'New' buttons. Below the navigation, there is a grid of solution cards. Each card features a representative image, a title, and a set of filters for Type (Policy, Action, Service, Product), Goal (Avoid, Shift, Improve), and Scale (Micro, Meso, Macro).

- Accessible Mobility:** Image of a blue wheelchair symbol on a road. Filters: Policy, Action, Service, Product; Shift; Micro, Meso, Macro.
- Active Mobility Incentives:** Image of a person riding a bicycle on a path. Filters: Policy; Shift; Meso, Macro.
- Autonomous Shuttles:** Image of a small, blue autonomous shuttle. Filters: PPS; Improve, Shift; Meso.
- Awareness Campaigns:** Image of a sign that says 'info'. Filters: Policy, Action; Avoid, Shift; Meso.
- Bike Highways:** Image of people riding bicycles on a dedicated path. Filters: Policy, Action; Shift; Micro, Meso.
- Bike Lanes:** Image of a street with a dedicated bike lane. Filters: Policy, Action; Shift; Meso, Micro.

Figure 90: Screenshot of urban mobility solution database

At the higher level, solutions are organised by themes, sorted in different types, different goals (Avoid, Shift, Improve), and scales. For most of the solutions, specific cases are added. The list of solutions can be found in Table 43 and the cases in Table 44.

Table 43: List of urban mobility solutions (more details via linked online database or on request)

Name	Category	Goal	Scale	Case?
Accessible Mobility	Action, Policy, Product, Service	Shift	Macro, Meso, Micro	yes
Active Mobility Incentives	Policy	Shift	Macro, Meso	yes
Autonomous Shuttles	Product-service system (PSS)	Improve, Shift	Meso	yes
Awareness Campaigns	Action, Policy	Avoid, Shift	Meso	yes
Bike Highways	Action, Policy	Shift	Meso, Micro	yes
Bike Lanes	Action, Policy	Shift	Meso, Micro	yes
Bike Parking	Action, Service	Shift	Micro	yes
Bike Repairing Station	Action, Service	Shift	Micro	yes
Bike Sharing	PSS, Service	Shift		yes

Name	Category	Goal	Scale	Case?
Bike Trailer (incl. Shared)	PSS, Product, Service	Shift	Meso, Micro	yes
Biogas Vehicles	Product	Improve	Macro	
Bus Priority	Action, Policy	Shift	Macro, Meso	yes
Cable Cars	Service	Improve, Shift	Micro	yes
Car Free Days	Action, Policy	Avoid, Shift	Macro, Meso, Micro	yes
Car Sharing	PSS, Service	Shift	Meso	yes
Cargo Bikes	Product, Service	Shift	Macro, Meso	yes
Carpooling	Action, Policy, Service	Improve, Shift	Macro, Meso, Micro	yes
Charging Infrastructure	PSS, Service	Improve	Meso	yes
Child-friendly Design	Action, Policy	Avoid, Shift	Micro	yes
Climate-based Traffic Management	Action, Policy	Shift	Meso, Micro	
Company Travel Plans	Action, Policy	Avoid, Shift	Micro	yes
Congestion Pricing	Policy	Shift	Meso	yes
Connectivity	Action, Service	Shift	Macro, Meso	yes
Coworking Space	Action, Policy, Service	Avoid	Macro, Meso, Micro	yes
Data Sharing	Action, Policy	Avoid, Improve, Shift	Macro, Meso, Micro	yes
Decentralisation / Polycentricity	Policy	Avoid	Macro, Meso	yes
Densification	Action, Policy	Avoid	Micro	yes
Electric Bikes (incl. shared)	PSS, Product, Service	Improve, Shift		yes
Electric Lightweight Vehicles	PSS, Product	Improve	Macro	yes
Electric Moped (incl. shared)	PPS, Product	Improve, Shift	Macro, Meso	yes
Electric Trotinettes (incl. shared)	PSS, Product, Service	Shift	Meso, Micro	yes
Electric Vehicles (EV)	Product	Improve	Macro	yes
European Mobility Week	Action	Avoid, Improve, Shift	Macro, Meso, Micro	
Free Public Transport	Policy	Shift	Meso	yes
Fuel Taxation	Policy	Improve, Shift	Macro	
Housing-as-a-Service	PSS, Service	Avoid		yes
Hybrid Vehicles	Product	Improve	Macro	
Hydrogen Vehicles	Product	Improve	Macro	
Information & Participation Platform	Action, Policy	Avoid, Shift	Macro, Meso	yes
Information & Signage	Action, Policy	Shift	Meso, Micro	yes
Integrated Mobility Management/Manager	Action	Avoid, Improve, Shift	Macro, Meso, Micro	
Intermodality	Action, Policy	Shift	Micro	
ITS for Public Transport	Service	Shift	Meso	

Name	Category	Goal	Scale	Case?
Lightrail Transit (LRT)	Service	Shift	Macro, Meso	yes
Living Lab / Innovation Playground	Action, Policy	Avoid, Improve, Shift	Micro	yes
Low-Emission Zones	Policy	Avoid, Improve, Shift	Meso, Micro	yes
Mass Transit / Public Transport	Policy, Service	Shift	Macro, Meso	yes
Metro	Policy, Service	Shift	Macro, Meso	
Mixed-Use	Action, Policy	Avoid	Micro	yes
Mobility Data Labs	Policy, Product, Service	Improve, Shift	Meso, Micro	yes
Mobility-as-a-Service	Service	Shift	Macro, Meso, Micro	yes
Multifunctional Commute	Action, Service	Shift	Micro	yes
Neighbourhood Centres	Action, Policy, Service	Avoid	Micro	yes
Opening Roads for Pedestrian	Action, Policy	Avoid, Shift	Meso, Micro	yes
Paratransit	Service	Improve, Shift	Meso, Micro	yes
Park-and-Ride	Policy, Service	Shift	Meso	yes
Parking Policies	Policy	Shift	Meso, Micro	
Peak Dispersion / Flex Schemes	Action, Policy, Service	Shift	Macro, Meso	
Placemaking	Action, Policy	Avoid, Shift	Micro	yes
Political Support	Action	Avoid, Shift	Macro, Meso, Micro	yes
Public Fleet Renewal	Policy	Improve	Macro, Meso	
Reducing Speeds	Policy	Improve, Shift	Meso, Micro	yes
Registration Licences	Policy	Shift	Macro	yes
Road-Space Rationing	Policy	Avoid	Meso	yes
Safe Mobility	Action, Policy	Shift	Macro, Meso, Micro	yes
Seamless Fee Payment	Policy, Product, Service	Shift	Macro, Meso, Micro	yes
Shared Autonomous Cars	Product	Improve	Macro	
Shared Spaces	Action, Policy	Improve, Shift	Micro	yes
Street Transformation	Action, Policy	Shift	Micro	yes
Sustainable City Logistics	Action, PPS, Policy, Product, Service	Improve	Macro, Meso, Micro	yes
Sustainable Tourism Mobility	Action, Policy, Product, Service	Shift	Macro, Meso, Micro	yes
Sustainable Urban Mobility Plans	Policy	Avoid, Shift	Macro, Meso	
Tele-Everything	Action, PSS, Policy, Service	Avoid	Macro	yes
Trackless Trams	Service	Improve	Meso	
Traffic Calming	Action, Policy	Improve, Shift	Meso, Micro	yes

Name	Category	Goal	Scale	Case?
Traffic Management	Policy	Shift	Meso, Micro	yes
Tram	Policy, Service	Shift	Meso	
Transit-Oriented Development	Policy	Avoid, Shift	Macro, Meso	yes
Transport Cards	Service	Shift	Meso	yes
Transportation Hubs	Action, Service	Avoid, Shift	Micro	yes
Trolley Bus Systems	Action, Policy	Improve		
Urban Escalators/Elevators	Action	Shift	Micro	yes
Urban Form	Action, Policy	Avoid, Shift	Meso, Micro	yes
Vehicle Ownership Taxation	Policy	Improve, Shift	Macro	yes
Vehicle-to-Grid (V2G) charging	PSS, Policy	Improve	Macro	
Vehicle-to-Infrastructure (V2I) communication	Service	Improve	Macro	
Vehicle-to-Vehicle (V2V) communication	Policy, Product	Improve	Macro	
Walkability	Action, Policy	Shift	Micro	yes
Water-based Transport	Action, Policy, Service	Improve, Shift	Macro, Meso	yes

Table 44: List of case studies linked to urban mobility solutions (links, descriptions, and visuals are available via linked online database or on request)

Name	Region	Related solution
Accessible Design	South-eastern Asia	Accessible Mobility
Tactile Station Paving, Netherlands	Western Europe	Accessible Mobility
accessBerlin App	Western Europe	Accessible Mobility
Bus Ramps, NY	Northern America	Accessible Mobility
Corporate Sustainable Mobility Plans	Southern Europe	Active Mobility Incentives
Carbon Footprint Applications	Western Europe	Active Mobility Incentives
Tax Deduction for Cycling to Work	Western Europe	Active Mobility Incentives
TransDev Shuttle	Western Europe	Autonomous Shuttles
Avenue, Lyon	Western Europe	Autonomous Shuttles
Bike Counter Copenhagen	Northern Europe	Awareness Campaigns
Sustainable Mobility Train, Italy	Southern Europe	Awareness Campaigns
Mobility App showing saved CO2	Western Europe	Awareness Campaigns
Elevate Bike Highway Copenhagen	Northern Europe	Bike Highways
Bike Highway La Defense	Western Europe	Bike Highways
Bike Lane Bins Copenhagen	Northern Europe	Bike Lanes
Winter Service Prioritisation Oulu	Northern Europe	Bike Lanes
Regional Bike Network Île-de-France	Western Europe	Bike Lanes
Bus Boarding Islands	Northern America	Bike Lanes
Highlighted Bike Lanes, NY	Northern America	Bike Lanes
Fiets & Service, Station Repair Shops Netherlands	Western Europe	Bike Parking
Velobox, France	Western Europe	Bike Parking
Station Bike Parking Garage Utrecht	Western Europe	Bike Parking

Name	Region	Related solution
Secured Bike Parking, Paris-Saclay	Western Europe	Bike Parking
Self-repair Stations, Dublin	Northern Europe	Bike Repairing Station
Bike Repair Voucher, Paris	Western Europe	Bike Repairing Station
Swapfiets, Netherlands/France/Germany	Western Europe	Bike Sharing
Velib, Paris	Western Europe	Bike Sharing
Itaú Bike Sharing, Brazil	Latin America & Carribbean	Bike Sharing
Child Bike Trailer Rental UK	Northern Europe	Bike Trailer
Bike Trailer Rental Aarhus	Northern Europe	Bike Trailer
Segregated Bus Lane, India	Southern Asia	Bus Priority
Highlighted Bus Lanes, Australia	Oceania	Bus Priority
Cable Cars Grenoble	Western Europe	Cable Cars
Cable Car, Algeria	Northern Africa	Cable Cars
Cable Car Network, La Paz	Latin America & Carribbean	Cable Cars
Weekly Car Free Days Jakarta	South-eastern Asia	Car Free Days
World Car Free Day, London	Northern Europe	Car Free Days
Car Free Sundays 1970s, Netherlands	Western Europe	Car Free Days
ShareNow, Paris	Western Europe	Car Sharing
Snappcar, Netherlands	Western Europe	Car Sharing
DIDIS – Cross-neighbourhood e-car- sharing	Western Europe	Car Sharing
Communal Cargo Bikes, Germany	Western Europe	Cargo Bikes
Cargo Rental, Paris	Western Europe	Cargo Bikes
Urban Arrow, Netherlands	Western Europe	Cargo Bikes
UPS Bike Cargo Delivery, US	Northern America	Cargo Bikes
BerlKönig, Berlin	Western Europe	Carpooling
BlaBlaCar	Western Europe	Carpooling
Ecov Carpooling Routes, France	Western Europe	Carpooling
Company Charger	Northern Europe	Charging Infrastructure
Park'in Saclay, France	Western Europe	Charging Infrastructure
Off-Peak Charging	Northern America	Charging Infrastructure
Children Consultation, Stockholm	Northern Europe	Child-friendly Design
Mobility Education	Western Europe	Child-friendly Design
Corners for Kids	Latin America & Carribbean	Child-friendly Design
Crossing Guards	Northern America	Child-friendly Design
Showers at Work	Western Europe	Company Travel Plans
Flexible Working Hours	Western Europe	Company Travel Plans
Electronic Road Pricing, Singapore	South-eastern Asia	Congestion Pricing
Congestion Charge, London	Northern Europe	Congestion Pricing
Congestion Pricing, NY	Northern America	Congestion Pricing
Free Charging in Public Transport	Northern Europe	Connectivity
Free Wifi in Public Transport	Western Europe	Connectivity
Public Libraries	Western Europe	Coworking Space
Self-organised Co-Working Spaces	Western Europe	Coworking Space

Name	Region	Related solution
WeWork	Northern America	Coworking Space
City Data Standard - Mobility (CDS-M)	Western Europe	Data Sharing
Loi d'orientation des mobilités, LOM, France	Western Europe	Data Sharing
Mobility platform maMob, Paris-Saclay	Western Europe	Data Sharing
Open API	Western Europe	Data Sharing
Data Lab MoveInSaclay	Western Europe	Data Sharing
Knowledge Cluster in Île-de-France	Western Europe	Decentralisation / Polycentricity
Randstad, Netherlands	Western Europe	Decentralisation / Polycentricity
Meu Bairro, Rio de Janeiro	Latin America & Caribbean	Decentralisation / Polycentricity
Urban Infill, Moscow	Eastern Europe	Densification
Vacancy Mapping, Riga	Northern Europe	Densification
Floating Houses	Western Europe	Densification
Adding Floors, Rotterdam	Western Europe	Densification
Floating School, Lagos	Sub-Saharan Africa	Densification
Zoov, Île-de-France	Western Europe	Electric Bikes
Financial Incentives, Île-de-France	Western Europe	Electric Bikes
Canta, Netherlands	Western Europe	Electric Lightweight Vehicles
Renault Twizy	Western Europe	Electric Lightweight Vehicles
LEV, Rotterdam	Western Europe	Electric Lightweight Vehicles
Cityscoot, France	Western Europe	Electric Moped
Felyx, Netherlands	Western Europe	Electric Moped
Tier, Paris	Western Europe	Electric Trottinettes
Dedicated Parking, Paris	Western Europe	Electric Trottinettes
Nissan Leaf	Eastern Asia	Electric Vehicles
VW T6.1 Electric	Western Europe	Electric Vehicles
Tesla	Northern America	Electric Vehicles
Free Senior Passes, Paris	Western Europe	Free Public Transport
Free Transport, Luxembourg	Western Europe	Free Public Transport
Dunkerque, France	Western Europe	Free Public Transport
Student Hotel	Western Europe	Housing-as-a-Service
Urban Campus, Paris	Western Europe	Housing-as-a-Service
Lodgis, Paris	Western Europe	Housing-as-a-Service
Vilnius' Mobility Platform/Game	Northern Europe	Information & Participation Platform
Teresina	Latin America & Caribbean	Information & Participation Platform
Colour Code for Bikes	Western Europe	Information & Signage
Enlarge Your Paris	Western Europe	Information & Signage
Lightrail Network Manila	South-eastern Asia	Lightrail Transit
RandstadRail Rotterdam - The Hague	Western Europe	Lightrail Transit
Lightrail Network, Addis Ababa	Sub-Saharan Africa	Lightrail Transit
WRI India Urban Experiments	Southern Asia	Living Lab / Innovation Playground
Sluppen Living Lab/Innovation Playground	Northern Europe	Living Lab / Innovation Playground

Name	Region	Related solution
European Network of Living Labs (ENoLL)	Western Europe	Living Lab / Innovation Playground
Paris-Saclay Innovation Playground	Western Europe	Living Lab / Innovation Playground
LEZ Brussels	Western Europe	Low-Emission Zones
LEZ Paris	Western Europe	Low-Emission Zones
Umweltplakette, Germany	Western Europe	Low-Emission Zones
ZOHO, Rotterdam	Western Europe	Mixed-Use
marineterrein amsterdam	Western Europe	Mobility Data Labs
MIT Urban Mobility Lab	Northern America	Mobility Data Labs
Whim	Northern Europe	Mobility-as-a-Service
Wiener Linien	Western Europe	Mobility-as-a-Service
Functional Train Division	Western Europe	Multifunctional Commute
Flexible Train Design	Western Europe	Multifunctional Commute
L'Arbrisseau Neighbourhood Centre	Western Europe	Neighbourhood Centres
Nordbahn-Halle, Vienna	Western Europe	Neighbourhood Centres
Cheonggyecheon, Seoul	Eastern Asia	Opening Roads for Pedestrian
Pedestrianised Bank of River Seine	Western Europe	Opening Roads for Pedestrian
Ola Electric Rickshaw	Southern Asia	Paratransit
GoMetro	Sub-Saharan Africa	Paratransit
Park&Ride, Amsterdam	Western Europe	Park-and-Ride
Terrace Support, Rotterdam	Western Europe	Placemaking
Ruas Completas	Latin America & Caribbean	Placemaking
Park(ing) Day	Northern America	Placemaking
Erion Veliaj	Southern Europe	Political Support
Mark Rutte	Western Europe	Political Support
Anne Hidalgo	Western Europe	Political Support
Yvonne Aki-Sawyerr OBE	Sub-Saharan Africa	Political Support
Enrique Peñalosa Londoño	Latin America & Caribbean	Political Support
Jaime Lerner	Latin America & Caribbean	Political Support
Country-wide Limit, Netherlands	Western Europe	Reducing Speeds
City-wide Speed Limit, Paris	Western Europe	Reducing Speeds
Registration Bidding, Shanghai	Eastern Asia	Registration Licences
Beijing Registration Lottery	Eastern Asia	Registration Licences
Odd/Even License Plates, São Paulo	Latin America & Caribbean	Road-Space Rationing
Women's Railroad Cars, India	Southern Asia	Safe Mobility
Street Lighting Safe Mobility	Western Europe	Safe Mobility
Safety-Campaign, Kampala	Sub-Saharan Africa	Safe Mobility
Tap&Pay	Western Europe	Seamless Fee Payment
Pay online	Western Europe	Seamless Fee Payment
Pay-by-SMS	Western Europe	Seamless Fee Payment
Superblock Barcelona	Western Europe	Shared Spaces
Parking Places, Vienna	Western Europe	Shared Spaces
Stationsplein, Rotterdam	Western Europe	Street Transformation

Name	Region	Related solution
Champs-Élysées (planned)	Western Europe	Street Transformation
Rua das Flores, Curitiba	Latin America & Caribbean	Street Transformation
Curb-side Management	Western Europe	Sustainable City Logistics
Pick-up Stations	Western Europe	Sustainable City Logistics
Electric Postal Services, Germany	Western Europe	Sustainable City Logistics
Bike Deliveries	Western Europe	Sustainable City Logistics
Bike Courier, Toronto	Northern America	Sustainable City Logistics
Lisbon's Tram as Tourist Attraction	Western Europe	Sustainable Tourism Mobility
Transport Passes, Paris	Western Europe	Sustainable Tourism Mobility
International Cycling Networks	Western Europe	Sustainable Tourism Mobility
Grocery Delivery	Northern Europe	Tele-Everything
Mixed-Education Programmes	Western Europe	Tele-Everything
Work-from-Home Policies	Northern America	Tele-Everything
MyStreet Moscow	Eastern Europe	Traffic Calming
Trees	Western Europe	Traffic Calming
Urban Street Art	Latin America & Caribbean	Traffic Calming
Operation Control Centre (OCC)	Western Europe	Traffic Management
Space Negotiation	Western Europe	Traffic Management
Multiagent-based Simulations	Western Europe	Traffic Management
Bus-responsive Traffic Management, Vancouver	Northern America	Traffic Management
TOD Dukuh Atas	South-eastern Asia	Transit-Oriented Development
Grand Paris Express	Western Europe	Transit-Oriented Development
TOD Curitiba	Latin America & Caribbean	Transit-Oriented Development
Shanghai Public Transport Card	Eastern Asia	Transport Cards
Veligo, Île-de-France	Western Europe	Transport Cards
OV Chip card, Netherlands	Western Europe	Transport Cards
Navigo Card, Île-de-France	Western Europe	Transport Cards
Châtelet-Les Halles	Western Europe	Transportation Hubs
Medellín's Cable Car Hubs	Latin America & Caribbean	Transportation Hubs
Escalators/Elevators, Vitoria-Gasteiz	Southern Europe	Urban Escalators/Elevators
La Defense Escalator, Île-de-France	Western Europe	Urban Escalators/Elevators
Medellin Urban Escalator	Latin America & Caribbean	Urban Escalators/Elevators
Human Scale	Southern Europe	Urban Form
Complexity	Western Europe	Urban Form
Block Size	Northern America	Urban Form
Power-dependent Taxation	Eastern Asia	Vehicle Ownership Taxation
Nocturnal Safety through Lively Facades	Western Europe	Walkability
Water Features	Western Europe	Walkability
Car Free City Centres	Western Europe	Walkability
15-Minute-City	Western Europe	Walkability
Promenade Plantée/Coulée Verte	Western Europe	Walkability
René-Dumont, Paris	Western Europe	Walkability

Name	Region	Related solution
Ground Floor Activation	Northern America	Walkability
New York High Line	Northern America	Walkability
Water Busses, Venice	Southern Europe	Water-based Transport
Free Ferry, Amsterdam	Western Europe	Water-based Transport
Navibus, Ferry Integration into PT, Rotterdam	Western Europe	Water-based Transport
Water Transport Lagos	Sub-Saharan Africa	Water-based Transport

AN.6: Supplementary data for Paris

AN.6.1: Case study description

Table 45: Mobility indicators for IDF 1976-2011 (based on EGT, Cerema 2019)

Year	Population	Household Motorisation Rate	Motorisation Rate of Total Population	Motorisation Rate of 18 and older	Car Occupancy Rate
1976	9,7 M	0.75	0.29	–	1.31
1983	9.9 M	0.87	0.35	–	1.32
1991	10.5 M	0.96	0.39	–	1.31
2002	11.1 M	0.91	0.38	0.50	1.30
2011	11.4 M	0.91	0.39	0.51	1.28

Table 46: Modal share in IDF 1976-2011 (based on EGT, Cerema 2019)

Year	Walking	Bike	Public urban transport	Other transport	2-wheeled vehicles	Car (driver)	Car (passenger)
1976	42 %	2 %	18 %	1 %	3 %	25 %	8 %
1983	38 %	1 %	19 %	1 %	2 %	29 %	9 %
1991	34 %	1 %	19 %	1 %	1 %	33 %	10 %
2002	34 %	1 %	18 %	1 %	1 %	33 %	10 %
2011	39 %	2 %	17 %	3 %	1 %	29 %	8 %

Table 47: Driving license and car ownership data 1976-2011 (based on EGT, Cerema 2019)

Year	Number of households	Population 18+	Population with driving license	Number of owned cars	Numbers of available cars
1976	3.8 M	–	–	2.9 M	2.9 M
1983	4.0 M	–	–	3.5 M	3.5 M
1991	4.3 M	–	–	4.1 M	4.1 M
2002	4.6 M	8.3 M	6.4 M	4.2 M	4.6 M
2011	4.9 M	8.7 M	6.8 M	4.5 M	4.9 M

Table 48: Development of average number and type of trips from 1976-2011 (based on EGT, Cerema 2019)

Year	Total population	Non-mobile population	Total no. of trips	Avg. moving time/day	Avg. trip duration	Trips per person
1976	8.7 M	11 %	30.3 M	87 min.	22.1 min.	3.49
1983	9.0 M	12 %	31.2 M	85 min.	21.7 min.	3.47
1991	9.5 M	6 %	33.2 M	88 min.	23.7 min.	3.49
2002	9.3 M	6 %	32.2 M	83 min.	22.7 min.	3.45
2011	9.6 M	8 %	35.9 M	95 min.	23.5 min.	3.73

Table 49: Average trips by mode (Paris Region, 2020, based on IDF Mobilities 2019)

Type of trips	Number of trips/weekday	Evolution 2010/2018
Walking	17.2 M	+ 9 %
Car	14.8 M	- 5 %
Public transport	9.4 M	+ 14 %
Bike	0.84 M	+ 30 %
Motorised 2-wheeler	0.42 M	-25 %
Others	0.38 M	+ 100 %
Total	43 M	+ 5 %

Table 50: Trips by public transport (Paris Region, 2020, based on IDF Mobilités, Optile, RATP, SCNF 2016/2017)

Mode of traffic	Lines	Millions of trips
Subway	16	1,560
Train – RER (SNCF – RATP)	14	1,409
Tramway	10	315
(Night) Bus	1,510	1,436
Total	1,550	4,720

AN.6.2: Supplementary files for persona-based reweighting for synthetic populations

Table 51: Codes of used variables (Source: EMP, 2021) Translated by author.

CODE	VAL.	VARIABLE
GARL	1	With parking space(s) (FR: Avec emplacement(s) de stationnement)
	2	Without parking space (FR: Sans emplacement de stationnement)
	Y	Except principal residence (FR: Hors résidence principale)
	Z	Except regular accommodation (FR: Hors logement ordinaire)
NA17	AZ	Agriculture, forestry and fishing (FR: Agriculture, sylviculture et pêche)
	C1	Manufacture of foodstuffs, beverages and tobacco products (FR: Fabrication de denrées alimentaires, de boissons et de produits à base de tabac)
	C2	Coking and refining (FR: Cokéfaction et raffinage)
	C3	Manufacture of electrical, electronic and computer equipment; machinery manufacturing (FR: Fabrication d'équipements électriques, électroniques, informatiques ; fabrication de machines)
	C4	Manufacture of transport equipment (FR: Fabrication de matériels de transport)
	C5	Manufacture of other industrial products (FR: Fabrication d'autres produits industriels)
	DE	Extractive industries, energy, water, waste management and depollution (FR: Industries extractives, énergie, eau, gestion des déchets et dépollution)
	FZ	Construction
	GZ	Trade; automobile and motorcycle repair (FR: Commerce ; réparation d'automobiles et de motocycles)
	HZ	Transport and storage (FR: Transports et entreposage)
	IZ	Accommodation and catering (FR: Hébergement et restauration)
	JZ	Information and/et communication
	KZ	Financial and insurance activities (FR: Activités financières et d'assurance)
	LZ	Real estate activities (FR: Activités immobilières)
	MN	Scientific and technical activities; administrative and support services (FR: Activités scientifiques et techniques ; services administratifs et de soutien)
	OQ	Public administration, education, human health and social action (FR: Administration publique, enseignement, santé humaine et action sociale)
RU	Other service activities (FR: Autres activités de services)	
ZZ	Not applicable (FR: Sans objet)	
STOCD	00	Ordinary unoccupied dwelling (FR: Logement ordinaire inoccupé)
	10	Owner (FR: Propriétaire)
	21	Tenant or sub-tenant of an empty non-HLM rented accommodation (FR: Locataire ou sous-locataire d'un logement loué vide non HLM)

CODE	VAL.	VARIABLE
	22	Tenant or sub-tenant of empty rented housing HLM (FR: Locataire ou sous-locataire d'un logement loué vide HLM)
	23	Tenant or sub-tenant of furnished rented accommodation or a hotel room (FR: Locataire ou sous-locataire d'un logement loué meublé ou d'une chambre d'hôtel)
	30	Free accommodation (FR: Logé gratuitement)
	ZZ	Except ordinary housing (FR: Hors logement ordinaire)
TRANS	1	No transportation (FR: Pas de transport)
	2	Walking (or rollerblading, scooter) (FR: Marche à pied (ou rollers, patinette))
	3	Bicycle (including electrically assisted) (FR: Vélo (y compris à assistance électrique))
	4	Motorised two-wheelers (FR: Deux-roues motorisé)
	5	Car, truck, van (FR: Voiture, camion, fourgonnette)
	6	Public transport (FR: Transports en commun)
	Z	Not applicable (FR: Sans objet)
TYPL	1	House (FR: Maison)
	2	Apartment (FR: Appartement)
	3	Residential accommodation (FR: Logement-foyer)
	4	Hotel room (FR: Chambre d'hôtel)
	5	Makeshift dwelling (FR: Habitation de fortune)
	6	Independent room (having its own entrance) (FR: Pièce indépendante (ayant sa propre entrée))
	Z	Excluding ordinary housing (FR: Hors logement ordinaire)
SURF	1	Less than 30 sqm (FR: Moins de 30 m2)
	2	Between 30 and 40 sqm (FR: De 30 à moins de 40 m2)
	3	Between 40 and 60 sqm (FR: De 40 à moins de 60 m2)
	4	Between 60 and 80 sqm (FR: De 60 à moins de 80 m2)
	5	Between 80 and 100 sqm (FR: De 80 à moins de 100 m2)
	6	Between 100 and 120 sqm (FR: De 100 à moins de 120 m2)
	7	120 sqm or more (FR: 120 m2 ou plus)
	Y	Except main residence (FR: Hors résidence principale)
	Z	Except regular accommodation (FR: Hors logement ordinaire)
COUPLE	1	Declared to live with a partner (FR: A déclaré vivre en couple)
	2	Declared to not live with a partner (FR: A déclaré ne pas vivre en couple)
CS1	1	Farmes (FR: Agriculteurs exploitants)
	2	Craftsmen, merchants and entrepreneurs (FR: Artisans, commerçants et chefs d'entreprise)
	3	Executives and higher intellectual professions (FR: Cadres et professions intellectuelles supérieures)
	4	Intermediate professions (FR: Professions Intermédiaires)
	5	Employees (FR: Employés)
	6	Workers (FR: Ouvriers)
	7	Pensioner (FR: Retraités)
	8	Other people without professional activity (FR: Autres personnes sans activité professionnelle)
DIPL	01	No schooling or stopping before the end of primary school (FR: Pas de scolarité ou arrêt avant la fin du primaire)
	02	No diploma and schooling interrupted at the end of primary school or before the end of college (FR: Aucun diplôme et scolarité interrompue à la fin du primaire ou avant la fin du college)
	03	No degree and schooling until the end of college or beyond (FR: Aucun diplôme et scolarité jusqu'à la fin du collège ou au-delà)
	11	CEP (certificate of primary studies) (FR: CEP (certificat d'études primaires))
	12	BEPC, elementary patent, college certificate, DNB (FR: BEPC, brevet élémentaire, brevet des collèges, DNB)
	13	CAP, BEP or diploma of equivalent level (FR: CAP, BEP ou diplôme de niveau équivalent)

CODE	VAL.	VARIABLE
	14	General or technological baccalaureate, higher patent, capacity in law, DAEU, ESEU (FR: Baccalauréat général ou technologique, brevet supérieur, capacité en droit, DAEU, ESEU)
	15	Vocational baccalaureate, professional, technician or teaching certificate, equivalent diploma (FR: Baccalauréat professionnel, brevet professionnel, de technicien ou d'enseignement, diplôme équivalent)
	16	BTS, DUT, Deug, Deust, bac+2 level health or social diploma, equivalent diploma (FR: BTS, DUT, Deug, Deust, diplôme de la santé ou du social de niveau bac+2, diplôme équivalent)
	17	Bachelor's degree, pro license, master's degree, equivalent diploma at bac+3 or bac+4 level (FR: Licence, licence pro, maîtrise, diplôme équivalent de niveau bac+3 ou bac+4)
	18	Master, DEA, DESS, high school diploma level bac+5, doctorate in health (FR: Master, DEA, DESS, diplôme grande école niveau bac+5, doctorat de santé)
	19	Research doctorate (excluding health) (FR: Doctorat de recherche (hors santé))
	ZZ	Out of scope (under 14) (FR: Hors champ (moins de 14 ans))
	YY	Except principal residence (FR: Hors résidence principale)
ETUD	1	Yes (FR: Oui)
	2	No (FR: Non)
ILETUD/ ILT	1	In the current municipality of residence (FR: Dans la commune de résidence actuelle)
	2	In another municipality of the department of residence (FR: Dans une autre commune du département de résidence)
	3	In another department of the region of residence (FR: Dans un autre département de la région de résidence)
	4	Outside the region of current residence: in mainland France (FR: Hors de la région de résidence actuelle : en métropole)
	5	Outside the region of current residence: in a DOM (FR: Hors de la région de résidence actuelle : dans un DOM)
	6	Outside the region of current residence: in a COM (FR: Hors de la région de résidence actuelle : dans une COM)
	7	Abroad (FR: À l'étranger)
	Z	Not applicable (no registration in an educational institution) (FR: Sans objet (pas d'inscription dans un établissement d'enseignement))
IMMI	1	Immigrant (FR: Immigrés)
	2	Non-immigrant (FR: Non immigrés)
INAI	1	In the department of current residence (FR: Dans le département de résidence actuelle)
	2	In another department of the region of current residence (FR: Dans un autre département de la région de résidence actuelle)
	3	Outside the region of current residence: in mainland France (FR: Hors de la région de résidence actuelle : en métropole)
	4	Outside the region of current residence: in a DOM (FR: Hors de la région de résidence actuelle : dans un DOM)
	5	Outside the region of current residence: in a TOM-COM (FR: Hors de la région de résidence actuelle : dans un TOM-COM)
	6	Abroad (FR: À l'étranger)
MOCO	11	Children of a couple (FR: Enfants d'un couple)
	12	Children from a single parent family (FR: Enfants d'une famille monoparentale)
	21	Adults of a childless couple (FR: Adultes d'un couple sans enfant)
	22	Adults of a couple with child(ren) (FR: Adultes d'un couple avec enfant(s))
	23	Adults from a single-parent family (FR: Adultes d'une famille monoparentale)
	31	Non-family in multi-person household (FR: Hors famille dans ménage de plusieurs personnes)
	32	People living alone (FR: Personnes vivant seules)

CODE	VAL.	VARIABLE
MODV	40	Persons living outside the household (FR: Personnes vivant hors ménage)
	11	Children of a couple (FR: Enfants d'un couple)
	12	Children from a single parent family (FR: Enfants d'une famille monoparentale)
	20	Single people under 40 years (FR: Personnes seules de moins de 40 ans)
	31	Members under 40 of a childless couple (FR: Membres de moins de 40 ans d'un couple sans enfant)
	32	Members of a couple with children (FR: Membres d'un couple avec enfants)
	33	Parents of a single-parent family (FR: Parents d'une famille monoparentale)
	40	Members aged 40 or over of a childless couple (FR: Membres de 40 ans ou plus d'un couple sans enfant)
	50	Single people aged 40 or over (FR: Personnes seules de 40 ans ou plus)
	60	Persons living outside the family in a multi-person household (FR: Personnes vivant hors famille dans un ménage de plusieurs personnes)
70	Persons living outside the household (FR: Personnes vivant hors ménage)	
SEXE	1	Men (FR: Hommes)
	2	Woman (FR: Femmes)
STAT_CONJ	1	Married (FR: Marié(e))
	2	In a registered partnership (FR: Pacsé(e))
	3	In concubinage or free union (FR: En concubinage ou union libre)
	4	Widow (FR: Veuf, Veuve)
	5	Divorced (FR: Divorcé(e))
	6	Single (FR: Célibataire)
STATR	1	Employees (FR: Salariés)
	2	Non salaried (FR: Non salariés)
	Z	Not applicable (FR: Sans objet)
TACT	11	Workers with a job, including apprenticeship or paid internship. (FR: Actifs ayant un emploi, y compris sous apprentissage ou en stage rémunéré.)
	12	Unemployed (FR: Chômeurs)
	21	Retired or pre-retired (FR: Retraités ou préretraités)
	22	Pupils, students, unpaid interns aged 14 or over (FR: Elèves, étudiants, stagiaires non rémunéré de 14 ans ou plus)
	23	Under 14 years (FR: Moins de 14 ans)
	24	Housewives or men (FR: Femmes ou hommes au foyer)
	25	Other inactive (FR: Autres inactifs)
	Z	Not applicable (FR: Sans objet)
TP	1	Full time (FR: Temps complet)
	2	Part time (FR: Temps partiel)
	Z	Not applicable (FR: Sans objet)

Table 52: Descriptive statistics for numeric variables

	Individual	Household level				
	AGED	NBPI	NE5FR	NE17FR	NPERR	VOIT
Min.	0	1	0	0	1	0
1st Qu.	20	3	0	0	2	0
Median	38	4	0	1.24	3	1
Mean	39	3.76	0.41	1.24	3.09	1.07
3rd Qu.	56	5	0.43	2	4	2
Max.	120	20	4	4	6	3

Table 53: Descriptive statistics for categorical data after population scaling, part 1

SEXE		COUPLE		ETUD	IMMI
Male	1,967k	Yes	6,004k	3,550k	2,719k
Female	2,119k	No	7,654k	10,109k	10,939k

Table 54: Descriptive statistics for categorical data after population scaling, part 2

GARL		TP		STATR	
Parking	7,905k	Fulltime	5,265k	Employee	7,526k
No parking	5,520k	Parttime	868k	Non-employee	5,504k
Distant	233k	NA	7,526k	NA	628k

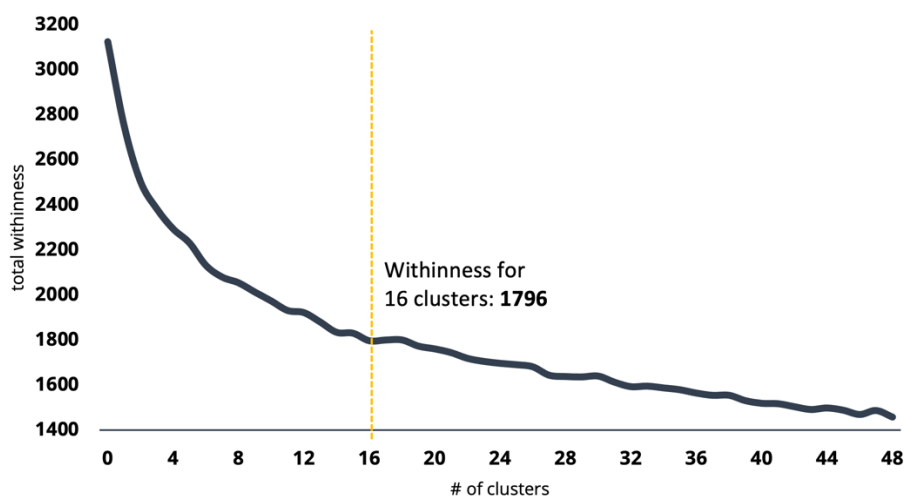


Figure 91: Scree test graph showing total within-ness (y-axis) for different number of clusters (x-axis)

Table 55: Information from mobility survey (EMP, 2021)

Variable	Description	Analysis
nb_dep	Number of trips per day	Sum
DUREE	Duration of the trip.	Mean, max, sum
MTEMPSMAP	Walking time during the trip	Mean, sum

Madeleine – *Retired* accountant

Age: 88
 Work: *Retired*
 Family: *Widow*
 Children: *None*
 Nationality: *French*
 Origin: *France, outside Paris*
 Education: *General bac.*
 Location: *3 Arr., Paris*



"I love walking through the streets on days like today. But when it rains I would like to take public transport but it's too expensive and inaccessible."

Personality



Goals

- Staying healthy
- Being able to safely get to her appointments and seeing friends
- Not losing her independence

Frustrations

- Expensive tickets for public transport as she is using it only from time to time
- She must often take longer ways for safety

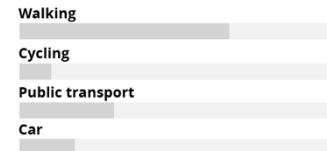
Trip narrative

On a *Friday morning in spring*, Madeleine leaves her *apartment* in Rue Portefoin after breakfast, at *around 10 AM*. It's a *fresh but sunny day* and she *decides to walk* to the Pantheon for an exhibition. She takes a longer, nicer route and *arrives after 1.5 hours*. After a few hours, *she leaves at 3 PM*. Now it's *nearly 20 degrees* and she decides to make a detour through the Jardin de Luxembourg. She *arrives back home at 4:30 PM*.

Personality



Preferred modes



Living situation

Housing type: *Apartment*
 Number of rooms: *2*
 Size: *40-60 sqm*
 Status: *Owner*
 Community: *Living alone*

Mobility situation

Car ownership: *No*
 Bike ownership: *No*
 License holder: *Yes*
 Transport card: *No*

Figure 92: Exemplary persona card for PP16. Everything written in *italic* is coming from underlying data. All other were deduced from it when and where possible. Persona format adapted from template by xtensio (2022)

Table 56: Initial, target, and actual proportional distributions of PP across scenarios




Scenario	Attribute	Value	Initial	Target	Result	Deviation
1	Household	Mean	2.992	2.992	2.993	0%
	Cars	Mean	1.057	1.110	1.105	0%
	Location	1	0.174	0.188	0.185	1%
	Location	2	0.173	0.185	0.188	-2%
	Location	3	0.346	0.306	0.310	-1%
	Location	nA	0.307	0.317	0.317	0%
2	Household	Mean	2.992	2.842	2.844	0%
	Cars	Mean	1.057	1.004	1.007	0%
	Location	1	0.174	0.188	0.187	0%
	Location	2	0.173	0.190	0.184	3%
	Location	3	0.346	0.319	0.320	-1%
	Location	nA	0.307	0.308	0.309	0%
3	Household	Mean	2.992	3.291	3.282	0%
	Cars	Mean	1.057	1.004	1.016	-1%
	Location	1	0.174	0.188	0.189	-1%
	Location	2	0.173	0.193	0.185	4%
	Location	3	0.346	0.325	0.322	1%



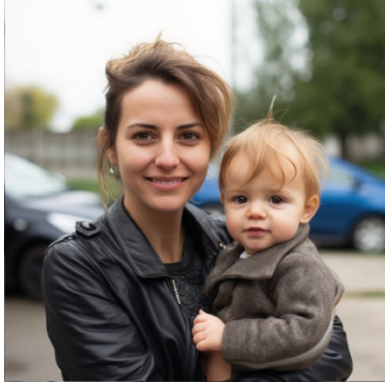

Scenario	Attribute	Value	Initial	Target	Result	Deviation
	Location	nA	0.307	0.303	0.303	0%
	Household	Mean	2.992	2.692	2.700	0%
	Cars	Mean	1.057	1.057	1.050	1%
4	Location	1	0.174	0.188	0.186	1%
	Location	2	0.173	0.182	0.184	-1%
	Location	3	0.346	0.300	0.307	-2%
	Location	nA	0.307	0.322	0.323	0%





AN.6.3: Personas for Greater Paris





Extended online database accessible at time of writing here: <https://urban-mobility-futures.notion.site/Personas-aa3b30f47c354220bc025dd7edb207cd?pvs=4>


Table 57: Overview of 16 data-driven personas for Greater Paris (CC BY 4.0)

Name/photo	Selected characteristics
	Household size 1 Child. <5 0 Relationship <i>Couple</i> Socio-prof. <i>Retired</i> Housing <i>Owner</i> Size <i>40-60 sqm</i> Cars 1 Parking Activity location
Madeleine Dubois	Primary mode
	Household size 2 Child. <5 0 Relationship <i>Couple</i> Socio-prof. <i>Without job</i> Housing <i>Tenant</i> Size <i>Less than 30 sqm</i> Cars 0 Parking Activity location
Samir Benali	Primary mode
	Household size 4 Child. <5 0 Relationship <i>Couple</i> Socio-prof. <i>Without job</i> Housing <i>Owner</i> Size <i>120 sqm or more</i> Cars 2 Parking <i>Parking spot</i> <i>Other municipality in department</i> Activity location
Nicolas Lefevre	Primary mode

Name/photo	Selected characteristics	
	Household size	3
	Child. <5	0
	Relationship	<i>Couple</i>
	Socio-prof.	<i>Intermediary professions</i>
	Housing	<i>Owner</i>
	Size	<i>80-100 sqm</i>
	Cars	2
	Parking	<i>Parking spot</i>
	Activity location	<i>Other municipality in department</i>
	Alexandre Mercier	Primary mode
	Household size	2
	Child. <5	0
	Relationship	
	Socio-prof.	<i>Higher educ/intel.</i>
	Housing	<i>Owner</i>
	Size	<i>60-80 sqm</i>
	Cars	1
	Parking	<i>Parking spot</i>
	Activity location	<i>Other department in region</i>
	Arnaud Delacroix	Primary mode
	Household size	4
	Child. <5	1
	Relationship	
	Socio-prof.	<i>Without job</i>
	Housing	<i>Tenant social housing</i>
	Size	<i>60-80 sqm</i>
	Cars	1
	Parking	<i>Parking spot</i>
	Activity location	
	Élodie Petit	Primary mode
	Household size	1
	Child. <5	0
	Relationship	<i>Couple</i>
	Socio-prof.	<i>Higher educ/intel.</i>
	Housing	<i>Tenant</i>
	Size	<i>Less than 30 sqm</i>
	Cars	0
	Parking	
	Activity location	<i>Same municipality</i>
	Fatima Bouchard	Primary mode

Name/photo	Selected characteristics
	<p>Household size 3</p> <p>Child. <5 0</p> <p>Relationship <i>Couple</i></p> <p>Socio-prof. <i>Employees</i></p> <p>Housing <i>Tenant social housing</i></p> <p>Size <i>60-80 sqm</i></p> <p>Cars 1</p> <p>Parking</p> <p>Activity location <i>Other department in region</i></p> <p>Primary mode <i>Public transport</i></p>
Isabelle Leclerc	
	<p>Household size 4</p> <p>Child. <5 1</p> <p>Relationship <i>Couple</i></p> <p>Socio-prof. <i>Without job</i></p> <p>Housing <i>Tenant social housing</i></p> <p>Size <i>80-100 sqm</i></p> <p>Cars 1</p> <p>Parking</p> <p>Activity location</p> <p>Primary mode</p>
Maxime Renaud	
	<p>Household size 4</p> <p>Child. <5 0</p> <p>Relationship</p> <p>Socio-prof. <i>Higher educ/intel.</i></p> <p>Housing <i>Owner</i></p> <p>Size <i>120 sqm or more</i></p> <p>Cars 2</p> <p>Parking <i>Parking spot</i></p> <p>Activity location <i>Other department in region</i></p> <p>Primary mode <i>Car</i></p>
Marie Durand	
	<p>Household size 3</p> <p>Child. <5 0</p> <p>Relationship <i>Couple</i></p> <p>Socio-prof. <i>Without job</i></p> <p>Housing <i>Tenant social housing</i></p> <p>Size <i>60-80 sqm</i></p> <p>Cars 1</p> <p>Parking</p> <p>Activity location <i>Same municipality</i></p> <p>Primary mode</p>
Benjamin Girard	

Name/photo	Selected characteristics	
	Household size	4
	Child. <5	1
	Relationship	
	Socio-prof.	<i>Employees</i>
	Housing	<i>Owner</i>
	Size	<i>60-80 sqm</i>
	Cars	1
Parking	<i>Parking spot</i>	
Amélie Martin	Activity location	<i>Other municipality in department</i>
	Primary mode	<i>Car</i>
	Household size	1
	Child. <5	0
	Relationship	<i>Couple</i>
	Socio-prof.	<i>Higher educ/intel.</i>
	Housing	<i>Tenant</i>
	Size	<i>40-60 sqm</i>
Cars	1	
Parking		
Laurent Dubois	Activity location	<i>Other department in region</i>
	Primary mode	<i>Public transport</i>
	Household size	4
	Child. <5	1
	Relationship	
	Socio-prof.	<i>Higher educ/intel.</i>
	Housing	<i>Owner</i>
	Size	<i>80-100 sqm</i>
Cars	1	
Parking		
Sébastien Moreau	Activity location	<i>Other department in region</i>
	Primary mode	<i>Public transport</i>
	Household size	4
	Child. <5	1
	Relationship	<i>Couple</i>
	Socio-prof.	<i>Without job</i>
	Housing	<i>Owner</i>
	Size	<i>60-80 sqm</i>
Cars	1	
Parking	<i>Parking spot</i>	
Céline Dupont	Activity location	<i>Same municipality</i>
	Primary mode	

Name/photo	Selected characteristics	
 <p>François Lefèvre</p>	Household size	2
	Child. <5	0
	Relationship	
	Socio-prof.	<i>Retired</i>
	Housing	<i>Owner</i>
	Size	<i>80-100 sqm</i>
	Cars	<i>1</i>
	Parking	<i>Parking spot</i>
	Activity location	
	Primary mode	

AN.6.4: Scenario assessment formulae and supplementary results

Remaining formulae for scenario assessment in IDF.

N : Total synthetic population taking trips within Paris-Saclay

T : Total daily trip time

D : Total daily distance

Indicator 5: Total daily trip time spent moving

Total trip time per day spent by population N

$$\sum_{n=1}^N T_n$$

(9)

Indicator 6: Average daily trip time

Total trip time per day spent by population divided by population

$$\frac{\sum_{n=1}^N T_n}{N}$$

(10)

Indicator 7: Average daily trip time per persona per scenario

For each persona: Sum of trip times divided by number of people of P.

$$\frac{\sum_{P=1}^{16} T_P}{N_P}$$

(11)

Indicator 8: Total daily trip distance

Total distance per day moved by population N

$$\sum_{n=1}^N D_n$$

(12)

Indicator 9: Average daily trip distance

Total trip distances per day spent by population divided by population

$$\frac{\sum_{n=1}^N D_n}{N}$$

(13)

Indicator 7: Average daily trip distance per persona per scenario

For each persona: Sum of trip distances divided by number of people of P.

$$\frac{\sum_{P=1}^{16} D_P}{N_P}$$

(14)

N :	Total synthetic population taking trips within Paris-Saclay
M :	Mode (Car, Passenger, Public Transport, SAEV)
P :	Persona (n=16)
KM _M :	km per mode
KM _{PP} :	km per persona
KM _{M,P} :	km per mode and persona
E _{Mi} :	Initial expenses per mode (only for SAEV)
E _M :	Expenses per mode (either per km or constant for public transport)
E _P :	Expenses per persona

Indicator 8: Total expenses per scenario

Sum of kilometres per mode times expenses per km per mode

$$\sum_{M=1}^4 KM_M E_M + E_{Mi}$$

(15)

Indicator 9: Average expenses per capita per scenario

Sum of kilometres per mode times expenses per km per mode divided by population

$$\frac{\sum_{M=1}^4 KM_M E_M + E_{Mi}}{N}$$

(16)

Indicator 10: Sum expenses per persona per scenario

For each persona: Sum of kilometres per mode times expenses per km per mode

$$\sum_{M=1}^4 \sum_{P=1}^{16} KM_{M,P} E_{M,P} + E_{Mi}$$

(17)

Indicator 11: Average expenses per persona per scenario

For each persona: Sum of kilometres per mode times expenses per km per mode divided by number of people of P.

$$\frac{\sum_{M=1}^4 \sum_{P=1}^{16} KM_{M,P} E_{M,P} + E_{Mi}}{N_P}$$

(18)

Continuation of result descriptions in main text: In Figure 93, we look at the total kilometres moved in the present and averaged per scenario group for 2030 and the modal shares and shift including active modes. The graph shows the changing total number of kilometres today (left), in 2030 without SAEVs (centre) and 2030 with SAEVs (right). We can observe a significant decrease of car kilometres, both individual and as passenger, and a comparatively low number of kilometres moved by SAEVs (purple).

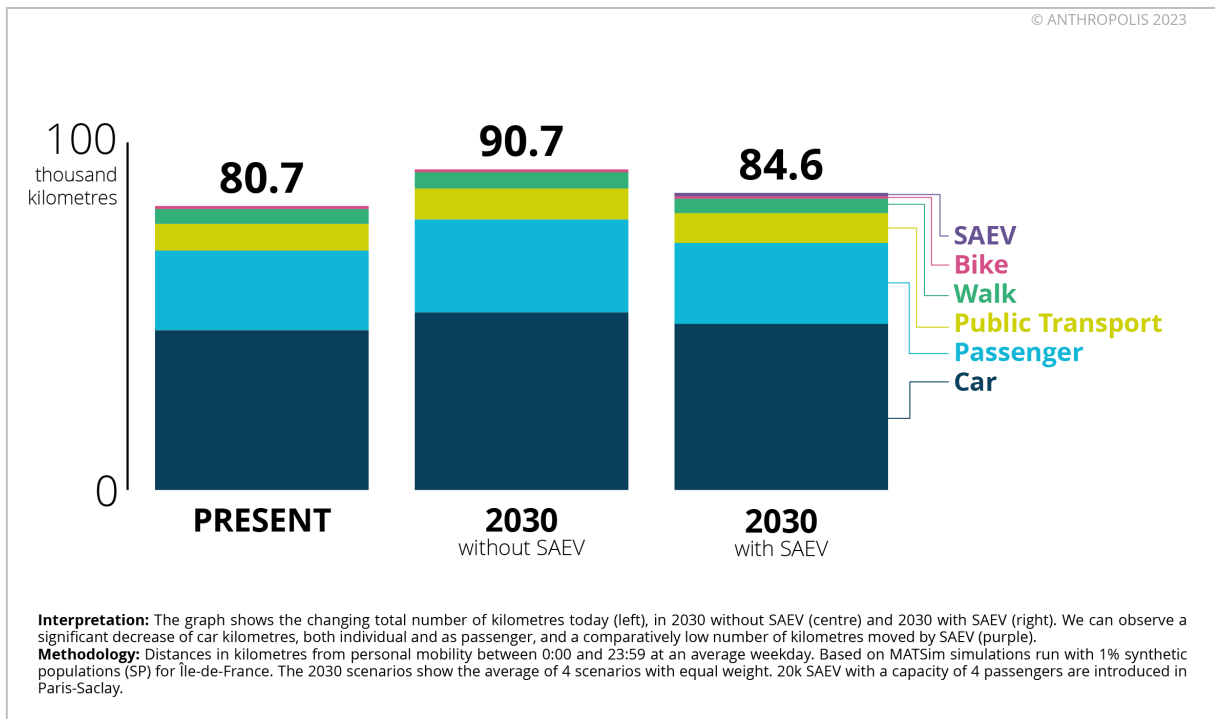


Figure 93: Daily commuting distances in Paris-Saclay. Impact of Shared Automatised Electric Vehicles (SAEV) (CC BY 4.0)

Figure 94 shows again the changing total number of kilometres today (left), in 2030 without SAEVs and with SAEVs disaggregated by scenario. We can observe a significant decrease of car kilometres, both individual and as passenger, and a comparatively low number of kilometres moved by SAEVs (purple). The aggregated impact varies from -4.1% in the 'At-an-easy-pace' scenario to -8.9% (or 7,000 km) in the 'Good-old-transport' scenario.

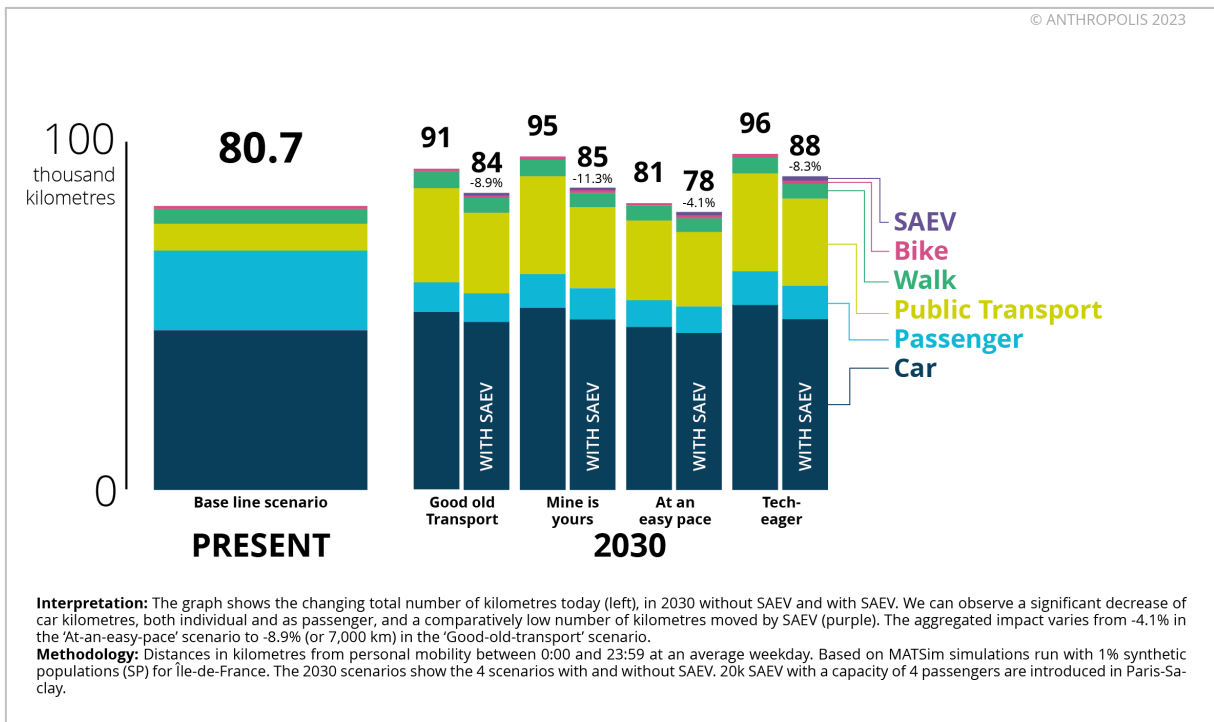


Figure 94: Daily commuting distances in Paris-Saclay. Impact of Shared Automatised Electric Vehicles (SAEV) (CC BY 4.0)

Regarding the time spent, Figure 95 indicates a daily average of about 63 minutes commuting per day for the present. For the 2030 scenarios without SAEVs, an average of 67 minutes is predicted. The introduction of SAEVs results in an average reduction of 4 minutes back to 63 minutes.

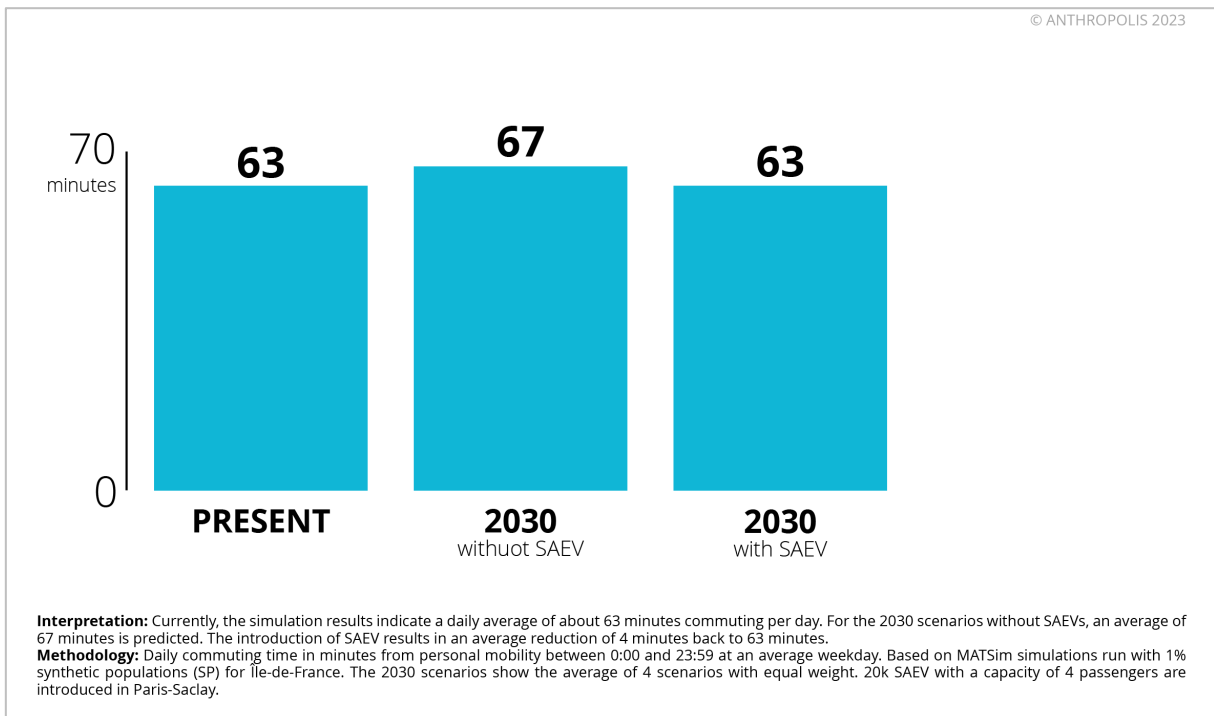


Figure 95: Average daily commuting time in Paris-Saclay. Impact of Shared Automatised Electric Vehicles (SAEV) (CC BY 4.0)

Figure 96 again disaggregates by scenario and shows for the 2030 scenarios without SAEVs, values between 71 ('Mine-is-yours') and 64 ('At-an-easy-pace') are predicted. The introduction of SAEVs results in a reduction between seven and one minutes.

While these numbers might appear small, it is important to reflect back on the average of about 60 minutes per day relatively constant across time and space, and the fact that an assumed average of four minutes saved for the total population at Île-de-France level of about 12.5 M people results in 833k hours per day, or assuming 216 working days per year and a working week of 37.5 hours, an equivalent of 4,8 million working weeks per year. In other words, the total yearly working time of 92k people. With the current minimum salary of 11.27 Euros/hour, this equals to an economic value of over two billion Euros.

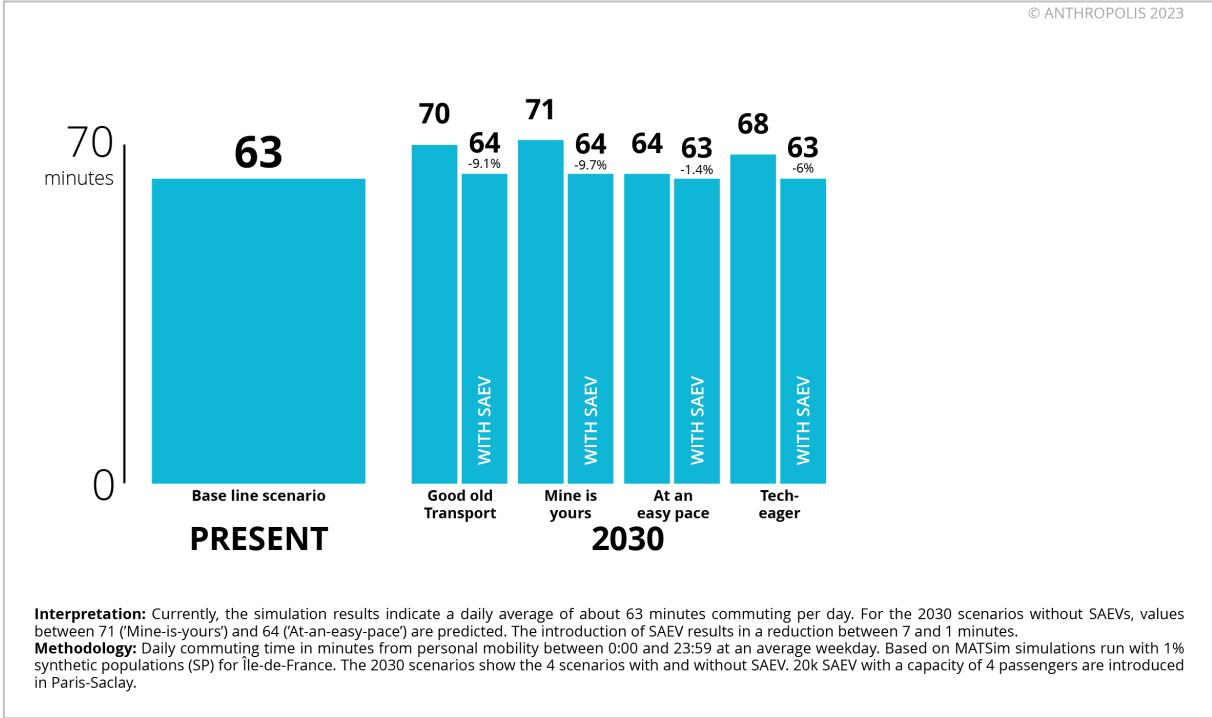


Figure 96: Average daily commuting time in Paris-Saclay. Impact of Shared Automatised Electric Vehicles (SAEV) (CC BY 4.0)

Lastly, we look at the actual individual mobility-related costs. Figure 97 indicates daily total expenses of 4.5 million Euros for the present situation. For the 2030 scenarios without SAEVs, an average of five million Euros is predicted. The introduction of SAEVs results in an average reduction of 200 thousand Euros, to 4.8 million Euros.

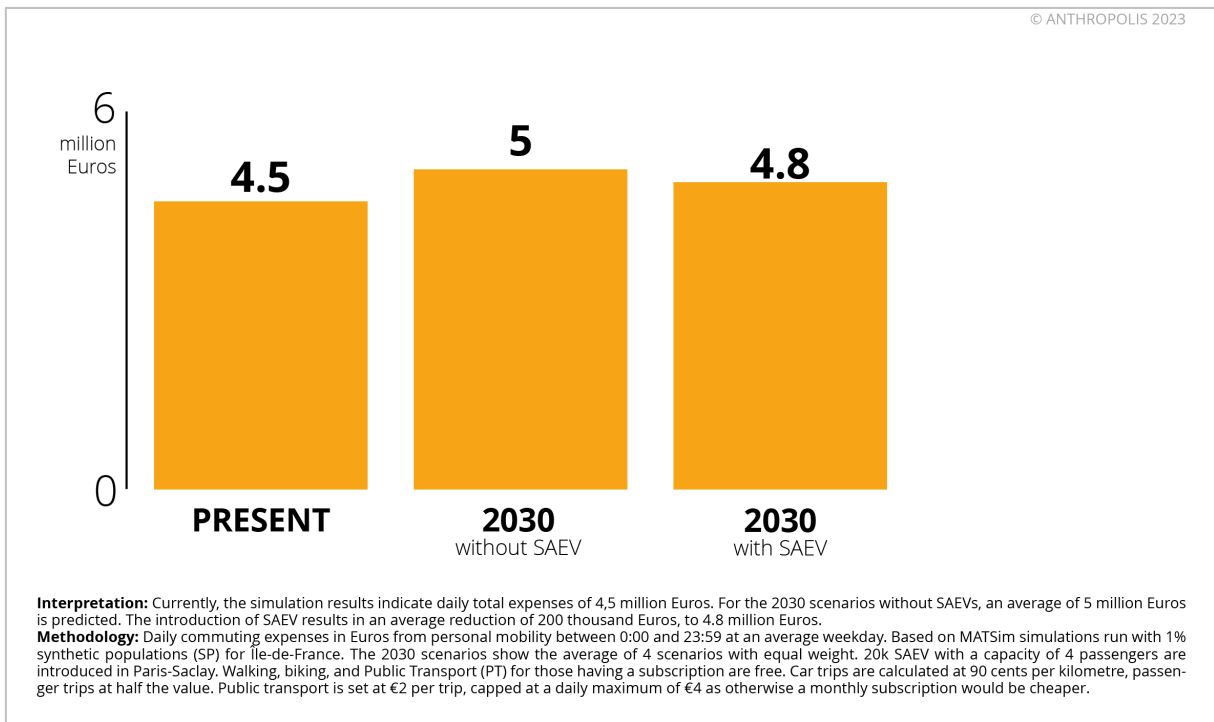


Figure 97: Daily mobility expenses in Paris-Saclay. Impact of Shared Automatised Electric Vehicles (SAEV) with constant mobility expenses (CC BY 4.0)

Figure 98 shows the disaggregated data, with values for the 2030 scenarios without SAEVs between 4.6 ('Mine-is-yours') and 5.3 million Euros ('Tech-eager'). The introduction of SAEVs results in a reduction between 100 to 300 thousand Euros.

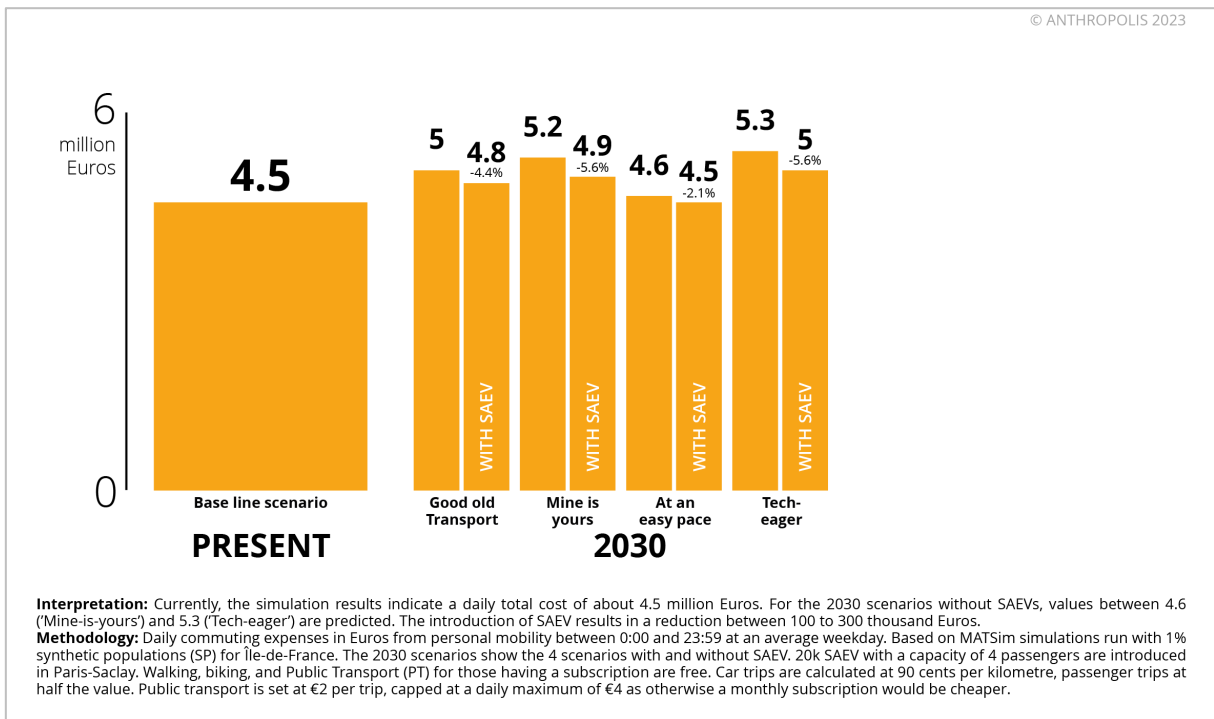


Figure 98: Daily mobility expenses in Paris-Saclay. Impact of Shared Automatised Electric Vehicles (SAEV) with constant mobility expenses (CC BY 4.0)

AN.6.5: Prompts for generation of scenario and persona visuals for online tool

The visuals for the sample scenarios and personas were generated with Midjourney. For each, a single prompt was written and one image from the first iteration was

chosen. The following lists all prompts and the outputs, as well as the highlighted choice.

Prompt

Output

Scenario 1: Realistic image without text of street from pedestrian perspective of urban development scenario for 2030 of innovation and university cluster south of Paris in France: Continuation of today’s development. The Saclay Plateau today is dominated by universities and technology-related institutions. Some residential buildings and other functions exist and are growing. Nevertheless, on weekend or holiday periods, the plateau remains mostly empty. Saclay 2.0 would be the continuation of the current growth. More university and technology functions would grow, complemented by more residential buildings. Nevertheless, by 2030, the character of the plateau remains to be largely linked to university’s seasonality and depending on the incoming commuters, primarily between Tuesday and Thursday and barely staying or utilising other functions on the plateau.



Scenario 2: Realistic image without text of street from pedestrian perspective of urban development scenario for 2030 of innovation and university cluster south of Paris in France: High-density, mixed-use neighbourhood. The second scenario is more optimistic on the integrated development of the plateau. It assumes that a large number of residential developments, going further than only student and international researcher housing, adds a critical mass of population density to allow for a variety of other functions to arise and remain active even in holiday seasons or weekends.



Prompt

Scenario 3: Realistic image without text of street from pedestrian perspective of urban development scenario for 2030 of innovation and university cluster south of Paris in France: Low-density, low diversity rural district. This scenario describes mostly the plateau as it has been since the 1970s. While more offices and universities are added, its functions and character remains primarily rural. Residential functions, as well as the accompanying other functions, remain limited and their growth stagnates, maintaining primarily the status quo of activity and functional mix.

Scenario 4: Realistic image without text of street from pedestrian perspective of urban development scenario for 2030 of innovation and university cluster south of Paris in France: High-density active core, surrounded by low-density. As a mix between the scenario 'Paris 2.0' and 'Rural Campus', this scenario is defined by overall low density and restricted developments. However, it has modern yet traditional French village cores with high level of mixed-use, walkability, and a range of bars and restaurants for students and other inhabitants of the plateau.

Persona 1: Realistic close-up image of a persona: Jacqueline, French woman aged 40 who works full-time at a technology company as a manager, does sport daily and stays healthy. She appreciates her privacy and has flexible work schedules. She doesn't want to walk too much because she carries lots of bags around, she prefers to cycle. She has no children and no partner and can be described as a workaholic. She is a bit concerned but not too much engaged with sustainability issues.

Persona 2: Realistic close-up image of a persona: Thierry is a 67-year-old man who visits the campus during the day to work. He is a professor and will soon be retired. He usually comes to the plateau from time to time to give guest lectures and lives inside Paris. He is not in charge of children. He usually uses public transport but lately is struggling due to a leg injury. He is very concerned by sustainability.

Output



Prompt

Output

Persona 3: Realistic close-up image of a persona: Adrian is a 35-year-old French man working part-time at a local supermarket in an administrative function. He is in charge of two kindergarten and one primary school child. He has a medium income level. He has many time constraints and lots of activities and scheduled meetings. He uses his car due to his complex daily movements and no possibility to deal with delays. Sustainability is not the priority in his choices due to several constraints.



Persona 4: Realistic close-up image of a persona: Rui is a 21-year-old female Chinese student. She is an international undergrad exchange student from China, studying at an engineering university. She lives on the campus in one of the student residencies. She mainly gets to her daily activities by walking and cycling because she cares about sustainability and has not many alternatives. It is also cheaper.



AN.7: Supplementary data for Cairo

AN.7.1: Cairo trend and uncertainties questionnaire

Table 58: Future trends for Cairo 2030, number of responses for likelihood categories

Trends	Likelihood			
	Not likely at all	Not likely	Likely	Very likely
<i>Continued population growth: Continuing growth to over 25 million by 2030</i>	0	0	4	11
<i>Urbanisation: More and more people living in or around urban and metropolitan centres</i>	0	1	3	11
Digitalisation: Technology being more widespread across sectors and more people using it on a regular basis	0	1	7	7
Mass transit: Expansion of the rail-based public transport system	0	3	10	2
Climate crises: Climate change leading to increasingly frequent and intense disasters or extreme events, such as heat waves	0	1	6	9
Aging population: An aging population requiring adapted solutions and a younger population more likely to embrace new mobility options	1	5	6	2
Growing middle class: Growing middle class driven by economic growth and the expansion of education and employment opportunities	8	5	2	0

Table 59: Future trends for Cairo 2030, number of responses for importance categories

Trends	Importance			
	Not important at all	Not important	Important	Very important
<i>Continued population growth: Continuing growth to over 25 million by 2030</i>	0	0	6	9
<i>Urbanisation: More and more people living in or around urban and metropolitan centres</i>	0	1	7	7
Digitalisation: Technology being more widespread across sectors and more people using it on a regular basis	0	3	5	7
Mass transit: Expansion of the rail-based public transport system	0	1	5	9

Trends	Importance			
	Not important at all	Not important	Important	Very important
Climate crises: Climate change leading to increasingly frequent and intense disasters or extreme events, such as heat waves	0	5	6	4
Aging population: An aging population requiring adapted solutions and a younger population more likely to embrace new mobility options	2	3	5	5
Growing middle class: Growing middle class driven by economic growth and the expansion of education and employment opportunities	0	4	6	5

Table 60: Future uncertainties for Cairo 2030, number of responses for likelihood categories

Uncertainties	Likelihood			
	Not likely at all	Not likely	Likely	Very likely
<i>Development of the housing market: E.g., continued urban sprawl and new towns or densification and infill</i>	0	3	4	8
New mobility solutions: E.g., Bus Rapid Transit (BRT), (trackless) trams, modern busses, and autonomous shuttles	0	2	5	7
<i>Private car ownership: Continuation of rise of car ownership or stagnation</i>	0	2	9	4
Shared mobility: E.g., car-, bike-, ride-sharing, and other shared mobility services, such as micro-mobility	0	6	4	5
Integrated multi-modal transportation: E.g., allowing people to switch between different modes of transport quickly and easily	0	2	6	6
Active mobility: E.g., walking and cycling as transport mode across different societal sectors, expansion of the bike-friendly infrastructure	1	1	5	7
15-minute city: E.g., mixed-use urban villages	2	3	4	5
Adoption of low-emission vehicles: E.g., electric cars, hybrid vehicles, and alternative fuel vehicles	1	4	5	4

Table 61: Future uncertainties for Cairo 2030, number of responses for importance categories

Uncertainties	Importance			
	Not important at all	Not important	Important	Very important
<i>Development of the housing market: E.g., continued urban sprawl and new towns or densification and infill</i>	0	0	6	9
New mobility solutions: E.g., Bus Rapid Transit (BRT), (trackless) trams, modern busses, and autonomous shuttles	0	1	7	7
<i>Private car ownership: Continuation of rise of car ownership or stagnation</i>	0	3	5	7
Shared mobility: E.g., car-, bike-, ride-sharing, and other shared mobility services, such as micro-mobility	0	1	5	9
Integrated multi-modal transportation: E.g., allowing people to switch between different modes of transport quickly and easily	0	5	6	4
Active mobility: E.g., walking and cycling as transport mode across different societal sectors, expansion of the bike-friendly infrastructure	2	3	5	5
15-minute city: E.g., mixed-use urban villages	0	4	6	5
Adoption of low-emission vehicles: E.g., electric cars, hybrid vehicles, and alternative fuel vehicles				

Table 62: Future uncertainties for Cairo 2030, ranked first by likelihood and perceived importance second

Uncertainties	Likelihood	Importance
<i>Development of the housing market: E.g., continued urban sprawl and new towns or densification and infill</i>	1 (highest)	2
New mobility solutions: E.g., Bus Rapid Transit (BRT), (trackless) trams, modern busses, and autonomous shuttles	2	1 (highest)
<i>Private car ownership: Continuation of rise of car ownership or stagnation</i>	3	4
Shared mobility: E.g., car-, bike-, ride-sharing, and other shared mobility services, such as micro-mobility	4	3
Integrated multi-modal transportation: E.g., allowing people to switch between different modes of transport quickly and easily	5	6
Active mobility: E.g., walking and cycling as transport mode across different societal sectors, expansion of the bike-friendly infrastructure	6	5
15-minute city: E.g., mixed-use urban villages	7	7
Adoption of low-emission vehicles: E.g., electric cars, hybrid vehicles, and alternative fuel vehicles	8 (lowest)	8 (lowest)

The prompts were: Please rank the following uncertainties on their likelihood, meaning which will most likely impact urban mobility in Cairo (options: Not likely at all, Not likely, Likely, Very likely). Please rank the following uncertainties on their

importance, meaning which might impact urban mobility in Cairo the most (options: Not important at all, Not important, Important, Very important)

AN.7.2: Cairo scenario descriptions

Scenario 2 | Disconnection



In a future scenario of *disconnection*, Greater Cairo faces challenges in connecting remote and low-density areas due to sprawl and low car ownership. Limited public transportation options leave residents isolated. To address this, community-based transport initiatives, such as shared shuttles and ride-sharing platforms, have emerged. Digitalisation plays a crucial role in improving connectivity, with ride-hailing apps and digital platforms facilitating mobility. Efforts also focus on enhancing internet infrastructure for digital inclusion. Despite the obstacles, Greater Cairo strives to bridge the disconnection, promoting inclusive transportation and digital access to improve the quality of life for all residents.

Scenario 3 | Gridlock



In a future scenario of high density and increasing car ownership, Greater Cairo grapples with severe traffic congestion and regular gridlocks in central urban areas. Despite the rise in car ownership, residents are abandoning cars due to their limited usefulness in the congested city. The government responds with investments in an expanded mass transit system, including an enhanced metro network and dedicated bus lanes. Smart transportation solutions such as intelligent traffic management systems, real-time navigation apps, and bike-sharing programs are introduced. Greater Cairo aims to alleviate congestion, promote sustainable transportation, and create a more liveable urban environment.

Scenario 4 | Urban Revival



Greater Cairo has undergone a transformation balancing high densification with reduced sprawl. With a population of 25.5 million, vertical growth dominates the cityscape with skyscrapers and multi-story residential complexes. Low rates of individual car ownership are counterbalanced by an extensive mass transit network, including a metro system, tram lines, and electric buses. Digitalization plays a vital role, with intelligent traffic management systems and real-time transportation information. The city's embrace of smart technologies has spurred a thriving ecosystem of tech start-ups and positioned Greater Cairo as a regional leader in sustainable urban development.

AN.7.3: Scenario localisation and population scaling

Table 63: Population density evolutions per area (qism) per scenario (based on data by CAPMAS and own elaborations)

Arabic name	English name	Area in sqkm	Distance from centre (km)	Population density (people/sqkm)			Population		
				2022	2030 Densification	2030 Sprawl	2022	2030 Densification	2030 Sprawl
قسم الظاهر	Qism El Zaher	3	1	26.8k	27.6k	26.3k	88.6k	91.1k	86.9k
قسم باب الشعريه	Qism Bab El Shaaria	1	1	61.1k	61.5k	57.9k	61.1k	61.5k	57.9k
قسم الشرابيه	Qism El Shrabia	4	1	53.3k	53.8k	50.8k	213.3k	215.2k	203.k
قسم شبرا	Qism Shobra	1	1	75.4k	75.7k	71.2k	75.4k	75.7k	71.2k
قسم الجماليه	Qism El Gmalia	2	2	22.1k	22.9k	22.k	44.3k	45.8k	43.9k

Arabic name	English name	Area in sqkm	Distance from centre (km)	Population density (people/sqkm)			Population		
				2022	2030 Densification	2030 Sprawl	2022	2030 Densification	2030 Sprawl
قسم الازبكيه	Qism El Azbakia	1	2	16.5k	17.3k	16.8k	16.5k	17.3k	16.8k
قسم الوايلي	Qism El Waily	5	2	19.5k	20.3k	19.5k	97.3k	101.4k	97.5k
قسم الموسكى	Qism El Mosky	1	2	25.4k	26.2k	25.k	25.4k	26.2k	25.k
قسم روض الفرج	Qism Rod El Farg	3	3	60.4k	60.8k	57.3k	181.2k	182.5k	171.9k
قسم حدائق القبه	Qism Hadaek El Koba	4	3	98.2k	98.3k	92.2k	392.8k	393.1k	368.7k
قسم الدرب الاحمر	Qism El Darb El Ahmr	2	3	38.2k	38.9k	36.8k	76.5k	77.8k	73.7k
قسم بولاق	Qism Bolak	3	3	25.7k	26.4k	25.2k	77.k	79.2k	75.7k
قسم الساحل	Qism El Sahel	6	3	62.6k	63.k	59.3k	375.5k	377.9k	355.8k
قسم عابدين	Qism Abdeen	2	3	30.1k	30.8k	29.3k	60.1k	61.5k	58.6k
قسم الزاويه الحمراء	Qism El Zawia El Hamra	5	4	79.4k	79.6k	74.8k	397.k	398.2k	374.1k
قسم منشاه ناصر	Qism Monshat Nasser	6	4	45.2k	45.8k	43.2k	271.1k	274.5k	259.5k
قسم قصر النيل	Qism Qasr El Nile	2	4	10.2k	11.1k	10.9k	20.3k	22.1k	21.9k
قسم الزمالك	Qism El Zamalek	3	4	4.2k	5.1k	5.4k	12.5k	15.3k	16.2k
قسم السيده زينب	Qism El Sayda Zeinb	4	5	46.1k	46.6k	44.1k	184.3k	186.5k	176.2k
قسم الاميرييه	Qism El Ameeria	4	5	49.5k	50.k	47.2k	198.k	200.1k	189.k
قسم ثان مدينه نصر	Qism 2nd Nasr City	17	5	5.1k	6.1k	6.3k	87.2k	103.2k	106.7k
قسم الزيتون	Qism El Zaytoun	4	6	48.5k	49.k	46.3k	194.1k	196.2k	185.3k
قسم امبابه	Qism Embaba	11	6	76.5k	76.8k	72.1k	841.4k	844.4k	793.6k
قسم الخليفه	Qism El El Khalifa	10	6	13.4k	14.2k	13.9k	133.9k	142.5k	139.k
قسم الدقى	Qism El Doki	5	6	16.2k	17.1k	16.5k	81.1k	85.3k	82.6k
قسم الوراق	Qism El Waraq	13	6	32.7k	33.3k	31.7k	424.6k	433.5k	412.k
قسم العجوزه	Qism El Agoza	7	6	42.9k	43.4k	41.1k	300.k	304.1k	287.7k
قسم مصر الجديده	Qism Heliopolis	9	6	18.1k	18.9k	18.2k	162.9k	170.2k	164.2k
قسم اول شبرا الخيمه	Qism 1st Shobra El Khema	10	7	58.k	58.4k	55.k	579.7k	584.2k	550.5k
قسم مصر القديمه	Qism Misr El Kadima	11	7	29.k	29.7k	28.3k	318.6k	326.5k	311.k
قسم المطريه	Qism El Mataria	7	8	105.8k	105.8k	99.2k	740.7k	740.7k	694.5k
قسم المقطم	Qism El Moqatam	29	8	7.8k	8.7k	8.8k	226.6k	253.k	253.8k
قسم ثان شبرا الخيمه	Qism 2nd Shobra El Khema	20	8	40.5k	41.1k	38.9k	809.3k	821.5k	777.8k
قسم بولاق الذكور	Qism Bolak El Dakror	13	9	91.6k	91.8k	86.1k	1191.2k	1192.	1119.6k
قسم عين شمس	Qism Ain Shamas	8	9	90.6k	90.8k	85.2k	725.k	726.1k	681.5k

Arabic name	English name	Area in sqkm	Distance from centre (km)	Population density (people/sqkm)			Population			
				2022	2030 Densification	2030 Sprawl	2022	2030 Densification	2030 Sprawl	
قسم الجيزه	Qism El Giza	13	9	25.1k	25.9k	24.7k	326.5k	336.3k	321.4k	
قسم دار السلام	Qism Dar El Salam	6	10	104.3k	104.3k	97.8k	625.8k	625.9k	586.9k	
قسم العمرانيه	Qism El Omrania	7	10	62.k	62.4k	58.7k	433.8k	436.7k	411.2k	
قسم اول مدينه نصر	Qism 1st Nasr City	77	11	11.3k	12.2k	12.k	872.7k	940.5k	924.k	
قسم البساتين	Qism El Bsateen	23	11	26.k	26.7k	25.5k	597.5k	614.6k	586.9k	
قسم الخصوص	Qism El Khosos	8	11	83.6k	83.8k	78.7k	669.1k	670.7k	629.9k	
قسم المعادى	Qism El Maadi	8	12	14.3k	15.1k	14.7k	114.2k	121.k	117.7k	
مركز اوسيم	Markaz Owssim	72	12	8.6k	9.5k	9.4k	615.9k	681.1k	679.3k	
قسم الطالبيه	Qism El Talbia	10	12	54.k	54.5k	51.4k	540.5k	545.3k	514.3k	
قسم المرج	Qism El Marg	18	13	55.k	55.5k	52.3k	990.5k	999.1k	942.k	
قسم قليوب	Qism Qaliob	21	14	9.k	10.k	9.9k	190.k	209.k	207.7k	
مركز كرداسه	Markaz Kerdasa	80	14	1.2k	2.2k	2.7k	96.7k	174.7k	212.4k	
قسم النزاهه	Qism El Nozha	68	14	4.2k	5.2k	5.4k	286.7k	351.1k	369.3k	
قسم الاهرام	Qism El Ahram	18	14	13.7k	14.5k	14.2k	246.1k	261.5k	254.9k	
قسم طره	Qism Tora	45	15	2.8k	3.7k	4.1k	125.1k	168.3k	184.8k	
مركز ابو النمرس	Markaz Abu El Nomros	71	16	6.4k	7.3k	7.5k	455.6k	521.4k	529.8k	
مركز قليوب	Markaz Qaliob	100	16	7.2k	8.1k	8.2k	719.5k	811.4k	818.k	
قسم اول السلام	Qism 1st El Salam	22	17	27.2k	28.k	26.7k	599.2k	615.3k	586.9k	
قسم الحوامديه	Qism El Hawamdia	17	19	14.2k	15.1k	14.7k	241.7k	256.2k	249.2k	
قسم الخانكه	Qism El Khanka	10	19	12.5k	13.3k	13.1k	124.8k	133.5k	130.5k	
قسم المعصره	Qism El Masara	14	20	19.5k	20.3k	19.5k	272.5k	283.8k	273.1k	
مركز القناطر الخيرييه	Markaz El Qanater El Kayria	110	20	5.5k	6.5k	6.6k	607.6k	710.4k	730.2k	
مركز الخانكه	Markaz El Khankah	124	20	5.k	5.9k	6.1k	614.9k	731.5k	758.4k	
قسم ثان السلام	Qism 2nd El Salam	11	20	14.8k	15.7k	15.2k	163.k	172.3k	167.3k	
قسم التجمع الخامس	Qism Eltagamoaa Khames	91	22	1.7k	2.7k	3.1k	157.6k	245.9k	285.6k	
قسم القطاميه	Qism El Qatmia	65	23	1.2k	2.2k	2.7k	79.8k	143.1k	173.7k	
قسم قها	Qism Qaha	12	24	3.7k	4.7k	5.k	44.7k	56.1k	59.7k	
قسم 15 مايو	Qism 15 Of May	76	26	1.7k	2.7k	3.1k	130.5k	204.2k	237.4k	
قسم حلوان	Qism Helwan	56	26	12.2k	13.1k	12.8k	682.7k	731.6k	716.4k	
قسم الشيخ زايد	Qism El Shikh Zaid	43	27	2.1k	3.k	3.4k	88.5k	130.1k	147.9k	
قسم اول 6 اكتوبر	Qism 1st October	6	125	27	.9k	1.9k	2.4k	114.8k	237.k	298.3k

Arabic name	English name	Area in sqkm	Distance from centre (km)	Population density (people/sqkm)			Population		
				2022	2030 Densification	2030 Sprawl	2022	2030 Densification	2030 Sprawl
مركز البدرشين	Markaz Badrashin El	135	28	4.9k	5.8k	6.1k	660.1k	787.1k	817.1k
قسم الشروق	Qism El Shorouk	175	29	.6k	1.6k	2.1k	105.8k	277.3k	367.k
قسم ثالث 6 أكتوبر	Qism 3rd 6 October	190	31	.3k	1.2k	1.8k	49.6k	236.5k	338.2k
قسم العبور	Qism El Obour	209	32	.7k	1.7k	2.2k	142.9k	347.6k	453.6k
قسم التجمع الاول	Qism Eltagamoaa Awl	186	32	.6k	1.6k	2.1k	111.8k	294.2k	389.5k
قسم التبين	Qism El Tbin	27	33	3.7k	4.6k	4.9k	99.2k	124.9k	133.1k
قسم ثان 6 أكتوبر	Qism 2nd 6 October	123	40	2.k	2.9k	3.3k	240.5k	359.5k	411.3k
قسم بدر	Qism Badr	104	46	.2k	1.2k	1.8k	23.9k	126.2k	182.1k
				Total			22.9M	25.5M	25.5M

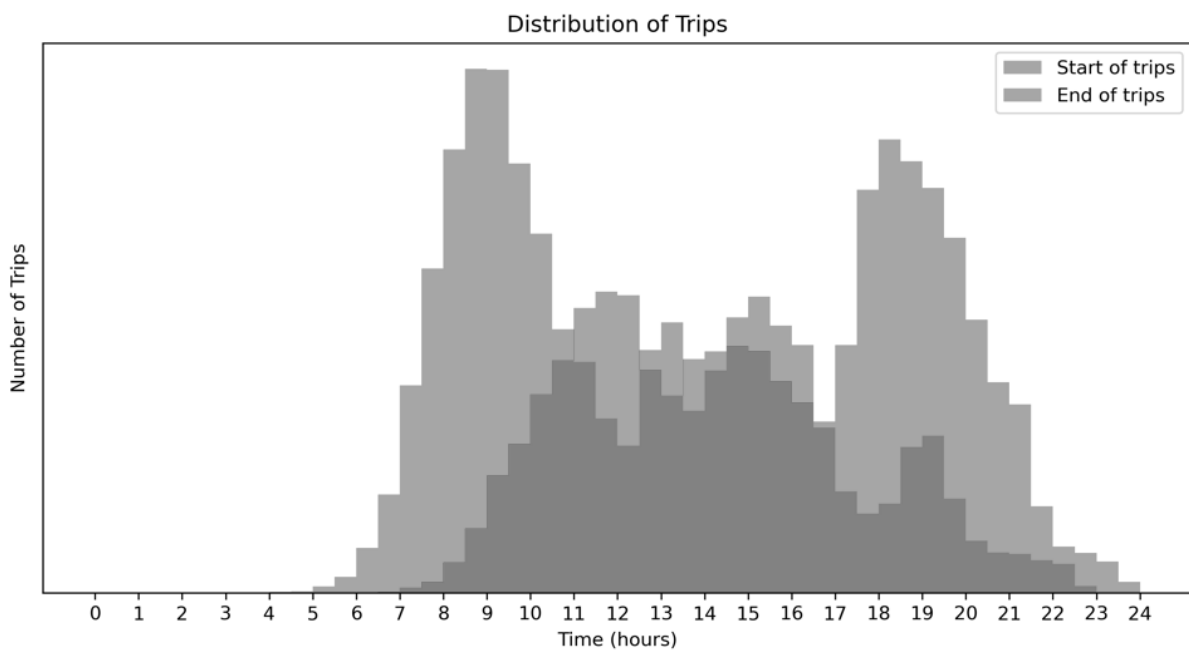


Figure 99: Synthesised distribution of start and end times of trips (CC BY 4.0)

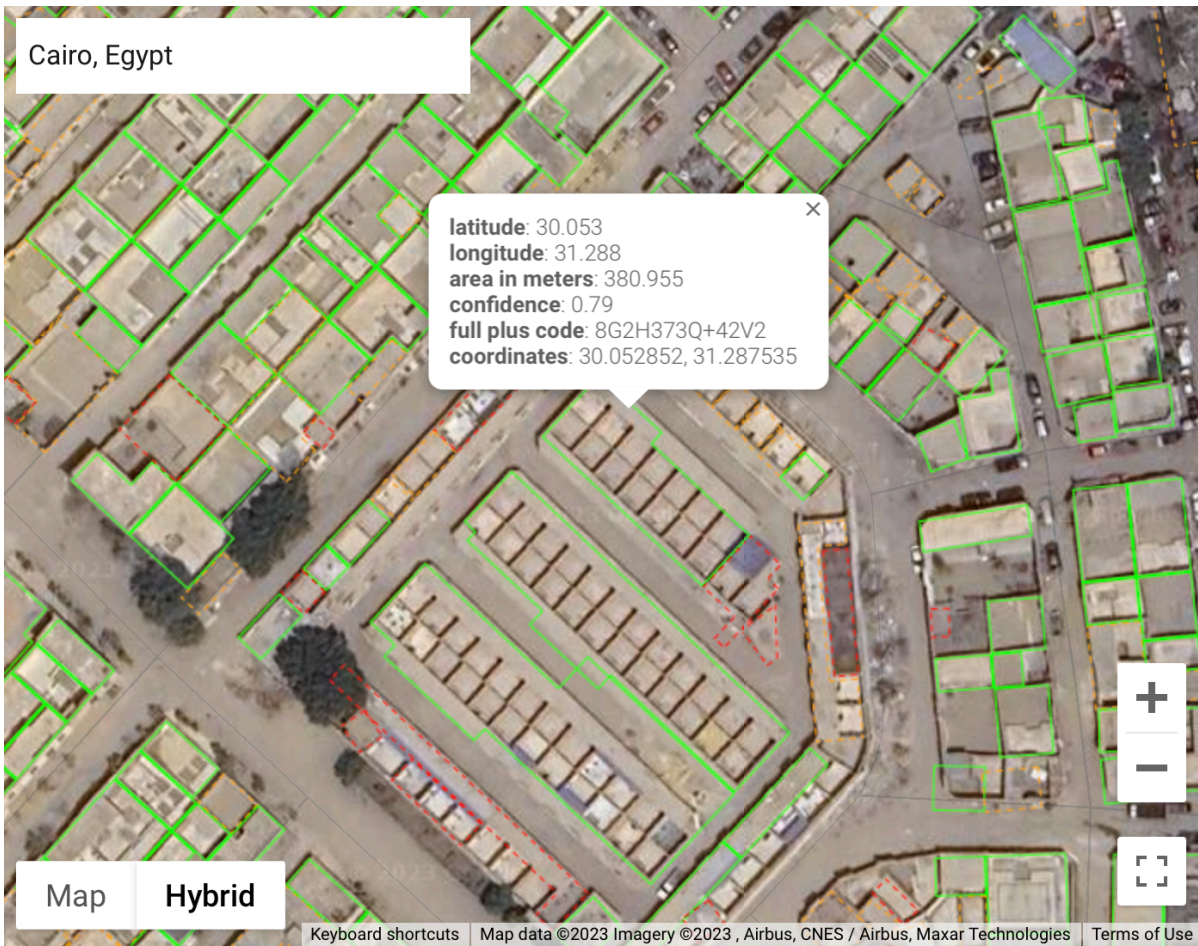


Figure 100: Screenshot of Google Open Buildings platform indicating confidence and visual interface (source: <https://sites.research.google/open-buildings/#explore>)

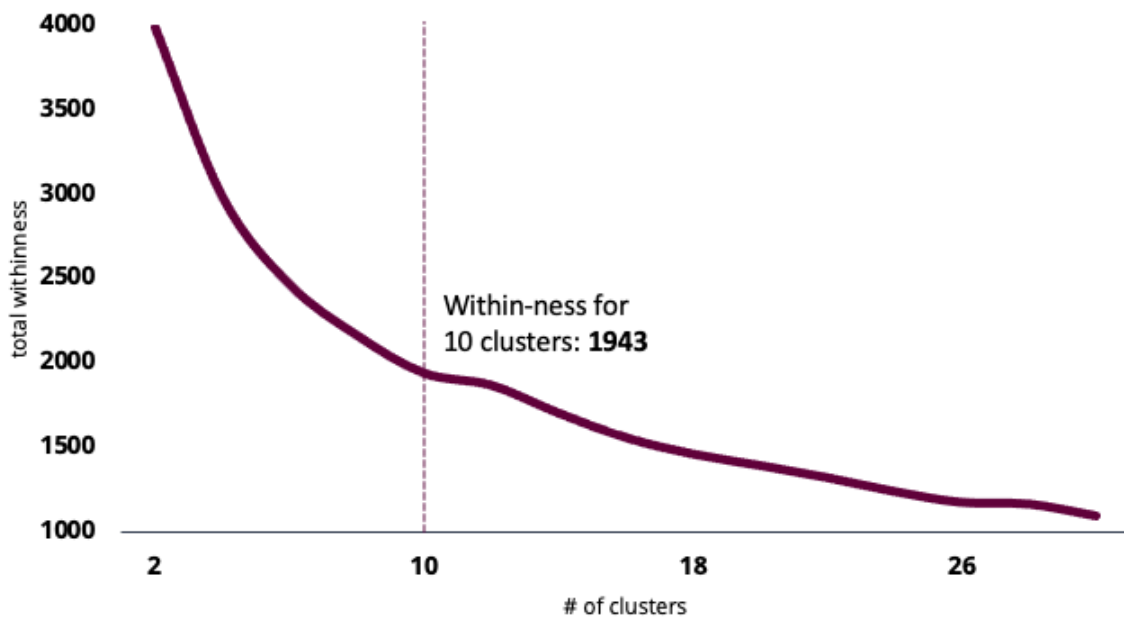


Figure 101: Within-ness for clustering with 2-30 clusters with highlighted location of 10 clusters (CC BY 4.0)

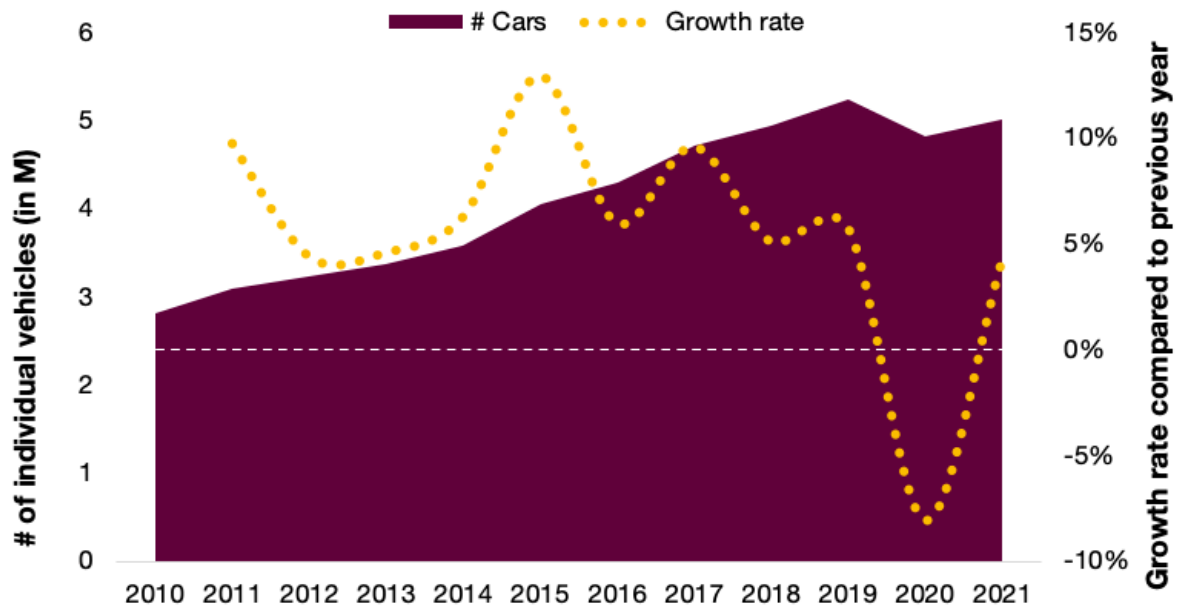


Figure 102: Number of individual cars in Egypt from 2010 to 2021 (left) and annual growth rates (right; Source: <https://www.ceicdata.com/en/egypt/number-of-registered-vehicles-annual/no-of-registered-vehicles-private-cars> [accessed 14 July 2023])

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APPENDICES

AP.1: Résumé en français

Le changement climatique évolue continuellement et plus rapidement que prévu, passant d'une peur à long terme à une réalité vécue. Les preuves scientifiques éclairent le rôle dominant des humains depuis le début de l'industrialisation jusqu'à aujourd'hui. La majorité des plus de 8 milliards de personnes vivent maintenant dans des villes qui génèrent plus des deux tiers des émissions mondiales. Cette tendance est à la hausse. Les principaux contributeurs sont les transports, le logement et l'énergie, avec une estimation de la contribution mondiale de la mobilité urbaine d'au moins 8 %. En plus des émissions, on observe une pollution locale, des niveaux d'accès très inéquitables aux opportunités, plus de 1,3 million de décès liés à la circulation et des millions de blessures graves, ainsi que des préoccupations croissantes concernant l'accès futur aux ressources telles que le pétrole ou les matériaux rares nécessaires aux véhicules électriques à batterie. Une multitude de solutions conceptuelles ainsi que des solutions testées existent pour inverser ou du moins atténuer ces impacts négatifs et contribuer à des transitions durables des systèmes de mobilité urbaine à l'échelle mondiale. Cependant, les processus de conception et de planification de ces systèmes et solutions potentiellement intégrés sont rendus plus complexes par divers facteurs, dont l'incertitude future. L'incapacité avérée de prévoir comment évolueront les personnes, les technologies, les villes et les systèmes urbains.

Ce projet de doctorat, ancré dans les sciences du design, a débuté avec l'objectif de développer des contributions méthodologiques pour répondre systématiquement aux défis socio-environnementaux tout en intégrant l'incertitude future dans le processus. Ou, comme formulé dans le projet initial, de « développer une approche méthodologique structurée pour produire des solutions de mobilité innovantes dans un territoire ». Menant le travail sur les futurs de la vie urbaine et de la mobilité à la Chaire Anthropolis, dirigé par Jakob Puchinger jusqu'en 2022 et ensuite par Flore Vallet, et au sein de l'équipe d'ingénierie de conception du Laboratoire Génie Industriel de CentraleSupélec, Université Paris-Saclay, le projet de doctorat a évolué grâce à un processus riche et collaboratif, incluant les partenaires du projet : la communauté d'agglomération Paris-Saclay, EDF, Engie, Groupe Renault et Nokia Bell Labs. Au cours de la deuxième moitié du projet, une visite de recherche en Égypte, rendue possible par la collaboration avec l'American University in Cairo et le cabinet de conseil en recherche Transport for Cairo, a permis d'appliquer et de reproduire les méthodes développées dans un contexte hétérogène représentatif de nombreux défis socio-environnementaux mentionnés précédemment. À partir de ce contexte et du problème posé, la question de recherche globale a été définie : *comment les processus de conception de solutions de mobilité centrées sur l'humain pour les futurs systèmes urbains peuvent-ils être soutenus ?*

Pour répondre à cette question, une approche mixte de méthode et de théorie ancrée a été mise en place, combinant une approche d'étude de cas appliquée aux deux contextes avec une série d'entretiens, d'ateliers et d'autres activités collaboratives, ainsi que quelques méthodes quantitatives. Cela a abouti à des contributions à un niveau conceptuel et méta-méthodologique, ainsi qu'à des méthodes et des outils plus techniques. Deux modèles sont proposés pour les systèmes urbains et les futurs, ainsi qu'un modèle conjoint pour travailler avec les futurs des systèmes de mobilité urbaine. Ensuite, un ensemble de trois méthodes et outils est proposé. Le cadre

méthodologique, ainsi que les outils développés, ont été créés et appliqués dans le contexte de Paris pour :

1. Définir le système de mobilité urbaine de Paris, constitué de personnes, d'infrastructures et de services,
2. Localiser des scénarios archétypaux dans le contexte français,
3. Créer un ensemble de personas et de populations synthétiques pour chacun des scénarios,
4. Appliquer un cadre de simulation de mobilité basée sur des agents aux scénarios pour évaluer l'impact potentiel des véhicules électriques automatisés partagés dans les services de mobilité intermodaux, et
5. Créer une plateforme d'aide à la décision en ligne en tant que deuxième outil d'évaluation rapide, éventuellement précédent, qui intègre l'incertitude future par le biais de scénarios.

Les principales étapes de la modélisation des systèmes, de la localisation des scénarios, de la création de personas et de populations synthétiques basées sur des scénarios, ainsi que des simulations de scénarios basées sur des agents ont été reproduites et validées dans le contexte du Grand Caire. Dans ce cas, les impacts socio-environnementaux d'un système de transport rapide en bus sur le périphérique, de l'amélioration de la marchabilité autour des stations de transport en commun et de la simplification de l'intermodalité entre les segments de transport en commun ont été testés.

Au niveau méthodologique, les deux études de cas d'application ont montré que le cadre développé peut contribuer à l'intégration structurée de l'incertitude dans l'évaluation et, par conséquent, les processus de conception des systèmes de mobilité urbaine ou de leurs composants. Au niveau thématique, les cas d'application ont souligné à Paris les avantages potentiels des véhicules électriques automatisés partagés sur les dimensions sociales, environnementales et économiques. Cependant, les impacts sont répartis de manière très hétérogène parmi 16 profils de personas identifiés et sont dépassés à la fois par les différences entre les scénarios résultant des changements socio-spatiaux, ainsi que par les gains d'efficacité technologique anticipés des véhicules. Dans le cas du Caire, les mêmes observations générales ont pu être faites. Cependant, les impacts d'un mélange des interventions testées ont été particulièrement significatifs pour les scénarios futurs qui anticipent une urbanisation continue et une augmentation du taux de possession de voitures individuelles - une combinaison qui peut être considérée comme une direction plus probable. Cela entraîne des recommandations politiques pour réduire l'urbanisation incontrôlée et la possession de voitures limitée, associées à un mélange ciblé de stratégies d'intervention pour amplifier l'utilisation et l'adoption de modes de transport en commun durables et efficaces.

Pour répondre à la question de recherche sur la manière de soutenir les processus de conception de solutions de mobilité centrées sur l'humain pour les futurs systèmes urbains, nous ne prétendons pas avoir trouvé une réponse claire ou omnipotente. Cependant, nous pouvons affirmer avec confiance qu'une approche de méthodes mixtes intégrant des scénarios, des personas et une réflexion complexe sur les systèmes dans les processus de conception de systèmes urbains peut contribuer à une meilleure préparation future et à de nouveaux leviers méthodologiques pour intégrer la durabilité et la centricité sur les personnes dans la conception.

Les résultats ont été présentés lors de sept conférences internationales, deux conférences nationales, deux forums de jeunes chercheurs, une école d'été, ont été enrichis par les résultats de deux projets d'étudiants en co-encadrement et ont donné lieu à neuf articles revus par des pairs (dont deux articles de revues), une contribution de rapport pour UN-Habitat et un livre dirigé sur les futurs de la mobilité urbaine durable en cours de publication.

En résumé, l'incertitude de l'avenir exige des approches structurées et novatrices pour les intégrer dans les processus et les méthodes de conception. Et bien que les futurs soient le sujet principal de ce projet de doctorat, leur pertinence découle du moment où les décisions de conception doivent être prises : aujourd'hui.

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AP.2: Glossary

TERM	DEFINITION	REFERENCE(S)
Accessibility	Capacity of individuals to access locations where various activities, such as education, employment, and recreational pursuits, are conducted. Highly dependent on land-use arrangements and transportation systems defining the ability of individuals or groups to reach specific destinations through a variety of transportation modes or their combinations.	Eltis, 2023 Geurs and van Wee, 2013, p. 128
Accessible Design	Accessible design is a design that focusses on the needs of people with disabilities.	
Action Plan	Also referred to as an implementation and budget plan, it “sets out how the plan, policy or measure will be turned into reality. The following information is typically included within an implementation plan: established priorities; implementation schedules; responsibilities; budgets and funding sources and risks and contingency plans.”	Eltis, 2023
Action Research	‘Action research has the dual aims of action and research. Through cycles of action and research a better understanding is obtained, while at the same time the organisation or programme under investigation is gradually changed. Action research is usually qualitative, data driven, participatory, and makes use of multiple data sources.’	Blessing and Chakrabarti, 2009, p. 273
Active Mobility	Active mobility refers to all types of human-powered mobility, notably that of walking, cycling, and using kick-scooters.	Cook et al., 2022
Anti-Personas	Anti-personas are fictional profiles that represent the opposite of a target audience or user group. They are used in design and marketing to understand the needs and preferences of individuals who are not part of the intended user base, helping to identify potential challenges and refine strategies.	Steele and Jia, 2007
Automated Vehicle	Often referred to as a self-driving or autonomous vehicle. An automobile equipped with advanced technology and sensors that enable it to navigate and operate without human intervention. The term automated is chosen over autonomous as the latter implies fully autonomy which is considered far from current progress.	
Black Swan	Rare and unexpected events or occurrences that have a significant and often far-reaching impact. These events are characterised by their unpredictability, potential to disrupt existing systems or beliefs, and the tendency to be rationalised in hindsight. Originating from the belief that all swans were white, until the discovery of black swans in Australia.	First references by Roman author Juvenal (55-140 AD), summarised by Hakan, 2021
Bounded Relativism	A perspective that acknowledges the existence of differing cultural or contextual viewpoints, but within certain limits or boundaries. It recognises that relativism, which asserts that truth or morality is subjective and dependent on individual or cultural factors, has limitations in situations where fundamental ethical or universal principles come into play. Bounded relativism suggests that while diverse viewpoints are recognised, there are overarching values or standards that should not be compromised.	
Business-As-Usual Scenario	The most common use of scenarios referring to a scenario which is the expected one if everything is done as expected or currently. The term is not used as it is perceived to oppose the idea of multiple, exploratory scenarios.	
City	A socio-spatial construct that is defined by socially, economically, and spatially predominantly continuous human settlements. It is oftentimes set equal with the administrative boundary but might be larger or only make up a smaller part thereof.	
Co-Creation	‘In a co-creation approach, heterogeneous actors collaborate to produce knowledge, instruments, technology, artefacts, policy, know-how, etc.’	ERA-NET Cofund Smart Urban Futures, In: INCLUSION, 2017
Commuting Area	A commuting area refers to the geographical region around an urban core within which people regularly travel for daily work, education, or other activities. It represents the area that individuals can reasonably access on a regular basis for their commuting needs, often influenced by transportation infrastructure and travel times.	OECD, 2019
Complex Adaptive Systems	Structures made up of numerous interconnected and interdependent elements that exhibit the ability to self-organise, learn, and evolve in response to their environment. These systems often involve feedback	Forrester, 1969; Batty, 1984

TERM	DEFINITION	REFERENCE(S)
	loops and non-linear interactions, leading to emergent behaviours that cannot be easily predicted from the behaviour of individual components.	
Complex Systems	In this context, equalled with Complex Adaptive Systems.	
Complex System Engineering	Design, development, and management of Complex Adaptive Systems.	
Cost Benefit/Effectiveness Analysis	Systematic approaches to evaluate the relative merits of different options by comparing their costs and benefits or outcomes. In Cost-Benefit Analysis, the monetary value of both costs and benefits are estimated and compared. The goal is to determine whether the benefits outweigh the costs. Cost-Effectiveness Analysis focuses on comparing the costs of options against a common outcome or effect, e.g., emissions.	
Delphi Method	Structured and iterative process used to gather insights and opinions from a group of experts or stakeholders. It involves a series of carefully designed questionnaires or surveys administered over multiple rounds, with controlled feedback mechanisms.	Dalkey and Helmer, 1963
Design Engineering	Multidisciplinary field focussing on creation and development of innovative and functional products, systems, or solutions. It involves a systematic and creative approach to problem-solving, encompassing various stages of the design process, from conceptualisation and prototyping to testing and refinement.	
Design	'To devise courses of action aimed at changing existing situations into preferred ones.'	Simon, 1969
Design Science	Systematic approach that applies scientific principles to create and develop solutions for practical problems. It involves the structured use of scientific methods and techniques to design and optimise systems, products, or processes, often with the aim of improving efficiency, effectiveness, and innovation.	
Epistemology	Branch of philosophy that deals with the study of knowledge itself, exploring questions about what constitutes knowledge, how it is acquired, justified, and evaluated, and how humans come to understand and interact with the world.	Moon and Blackman, 2014
Exploratory Futures	Type of futures that aim to explore and compare different futures instead of focusing on their probability. Used frequently in combination with scenarios.	Dator, 2019
Forecasts	Predictions or estimates of future events, trends, or outcomes based on available information and analysis, commonly by extrapolating from the past. Conceptually, forecasts and futures constitute two opposing approaches with different epistemological foundations.	
Functional Urban Area	A geographical area that comprises a city or a core urban area and its surrounding commuter zones, as well as interconnected and interdependent economic, social, and functional relationships	OECD, 2019
Future Personas	Future persona is a scenario-specific fictional individual living in the future scenario she is meant to depict.	Fergnani, 2019
Futures Studies	Futures studies is the interdisciplinary study of socio-technical systems, their possible (and preferred) futures, their origins in the past, and their formation in the present.	Dator, 2019
Gamification	Application of game elements, such as competition, challenges, rewards, and interactivity, to non-game contexts or activities. Often applied in learning and capacity development activities.	
Grounded Theory	Qualitative research methodology used to develop theories or explanations based on systematically collected data from real-world observations.	Collins and Stockton, 2018
Hinterland	Area surrounding an urban centre that is influenced by and connected to the city's activities, resources, and services. It includes the regions from which the city draws resources, such as labour, raw materials, and food, as well as the areas where people live and commute to the city for work or other purposes.	
Hyper Mobility	Term describing the increasing phenomenon that some people, mostly the elite, moves faster, farther, and more frequently, enabled by increasing technological advancement in the transport sector.	Gössling et al., 2009

TERM	DEFINITION	REFERENCE(S)
Immobility	The counterpart to mobility. Life can be understood as immobility interrupted by moments of mobility or vice versa. The consideration thereof can help modelling and understanding urban mobility.	Vendemmia, 2015
Inclusive (Mobility)	“To consider the needs of individuals who are socially excluded, e.g., older and disabled individuals”	INCLUSION, 2017
Individual Mobility	Not to be confused with <i>Personal Mobility</i> . Counterpart to <i>Collective Mobility</i> .	
Interdisciplinarity	‘Interdisciplinary studies are those in which concerted action and integration are accepted by researchers in different disciplines as a means to achieve a shared goal that usually is a common subject of study.’	Lawrence, 2010, p. 126
Intermediary design objects	Objects that ‘lies in between several elements, several actors or successive stages of a work process (intermediary result) [...] a general way of designating drawings, files, prototypes which mark the transition from one stage to another, circulate from one group to another or around which various actors and instruments revolve’	Vinck and Jeantet, 1995, p. 118
Intermodality	Intermodal transport refers to ‘transportation by more than one form of carrier during a single journey’	Goetz, 2009
Living Lab	‘The gathering of public-private partnerships in which businesses, researchers, authorities, and citizens work together for the creation, validation, and test of new services, business ideas, markets, and technologies in real life contexts.’	INCLUSION, 2017
MaaS	‘MaaS is an innovation in mobility management, where the revolution resides in the integration of transport services, digital and physical infrastructure, new actors, and other technologies in one digital platform with a single account to simplify usage. This platform allows users to access the available mobility options and to customize [sic] their trips by combining different modes according to their needs and desires. This user-centric platform permits the selection of trips with the available / selected mobility services and takes into account the users’ territorial context.’	Reyes Madrigal and Puchinger, 2021, p. 39.
Metropolis	Primarily administrative entity larger than the urban core. Not to be confused with <i>Metropolitan Area</i> .	
Metropolitan Area	‘A city and its commuting zone’ which ‘generates a daily flow of people into the city and back’, ‘often referred to as “functional” because it captures the full economic function of a city’ (EC, 2020d, not equal to a metropolis which is often used as a term for a primary (capital) city of large extent.	EC, 2020d
Micromobility	Modes that involve small, lightweight vehicles designed for short-distance travel within urban areas. These vehicles are typically intended for individual use and provide an alternative to traditional modes of transportation like cars or public transit for short trips.	
Mobilities	‘Mobilities examines the large-scale movements of people, objects, capital, and information across the world, as well as more local processes of daily transportation, movement through public and private space and the travel of material objects in everyday life. New transportation and digital infrastructures and novel social and cultural practices pose important challenges for coordinating and governing mobilities and for mobility rights and questions of ‘access’.’	Journal scope description of ‘Mobilities’ (link)
Mobility	Ability and ease of movement of people, goods, or information within and between different locations or points.	
Mobility Modes	Different methods or forms of transportation and movement that individuals or goods can use to travel from one place to another.	
Modal Share	Also known as mode share or modal split, refers to the distribution of people or goods using different transportation modes within a specific geographical area or for a particular type of trip.	
Motility	Potential and actual capacity of goods, information or people to be mobile both geographically and socially.	Kaufmann, 2002
Agent-Based Simulation	Computational modelling technique used to simulate and study complex systems by representing individual entities (agents) and their interactions within a simulated environment.	Abar et al., 2017

TERM	DEFINITION	REFERENCE(S)
Multidisciplinarity	Collaboration of knowledge, methods, and perspectives from multiple different disciplines or fields of study to address complex problems or explore diverse aspects of a subject.	Lawrence, 2010
Multimodality	Use of various modes over the course of a week.	Nobis, 2010
Normative Futures	Potential scenarios or outcomes that are guided by desirable values, ethical principles, or established norms.	
Ontology	Philosophical study of the nature of being, existence, and reality. It delves into questions about what exists, the fundamental categories of existence, and the relationships between different entities.	Lawrence, 2010
Paratransit	‘A collective transport service (public or private) that operates alongside the primary collective transport services and includes services that are demand responsive and provide shared rides.’	INCLUSION, 2017
People-Centred Design	‘An inclusive design approach for products and services which puts humans’ needs in the centre, involves them actively through co-creation, and assesses the systemic impacts on humans in present and future societies.’	Gall et al., 2021a
Peri-urban	Transitional zone or area that lies between urban and rural regions. Cf. hinterland and commuting zone.	
Personal Mobility	Mobility of people to move between home and other locations for personal reasons, including work, but excluding deliveries and other logistics-related types of mobility and transport.	
Personas	Fictional representations or profiles of specific user types or individuals created to better understand and design for the needs, preferences, behaviours, and characteristics of a target audience.	Pruitt and Grudin, 2003
Place-Based	Approach or perspective that emphasizes the unique characteristics, context, and attributes of a specific location or geographic area.	
Positivism	Philosophical and scientific approach that emphasises the empirical observation and measurement of phenomena as the primary means of acquiring knowledge. It asserts that reliable knowledge can be gained through the systematic collection and analysis of observable facts and data, and that these facts can be used to formulate general laws or principles that govern the behaviour of the natural and social worlds.	Moon and Blackman, 2014
Post-Positivism	Philosophical stance that challenges some of the foundational assumptions of positivism while still valuing empirical research and scientific inquiry. It recognises that complete objectivity and neutrality in research may be difficult to achieve due to the influence of human subjectivity, context, and interpretation.	Moon and Blackman, 2014
Pragmatism	Philosophical approach that emphasizes practicality, usefulness, and real-world consequences as criteria for evaluating the validity and meaning of ideas, beliefs, or theories. Pragmatists focus on the practical outcomes and effects of actions, concepts, or beliefs, rather than relying solely on abstract principles or metaphysical considerations.	Moon and Blackman, 2014
Predictive Futures	Cf. forecasts.	
Problem-based approach	Method that centres around solving real-world problems or challenges as a primary means of acquiring knowledge and skills.	
Scenarios (of futures)	Detailed and plausible narratives or stories that describe potential future situations, events, or developments and exist in sets of distinct alternatives.	Spaniol and Rowland, 2018
Self-planned Settlement	Urban areas that are planned by their inhabitants instead of formal planning mechanisms. Also referred to as unplanned or informal settlements, or favelas/slums.	
Serious Gaming	Use of games and game-like activities for purposes beyond entertainment, often with educational or problem-solving objectives. Cf. Gamification.	
Shared Mobility	‘The shared use of a vehicle, bicycle, or other mode – enables users to gain short-term access to transportation modes on an “as-needed” basis. Shared mobility includes carsharing, bike-sharing, ridesharing, and on-demand ride services. It can also include alternative transit services, such as paratransit, shuttles, and private transit services.’	INCLUSION, 2017
Social Mobility	‘Social mobility refers to the shift in an individual’s social status from one status to another. The shift can either be higher, lower, inter-	Sorokin, cf. CFI Team, 2023 (link)

TERM	DEFINITION	REFERENCE(S)
	generational, or intra-generational, and it cannot necessarily be determined if the change is for good or bad.'	
Social Practices	Habitual, repeated, and patterned activities, behaviours, and interactions that individuals and groups engage in as part of their daily lives. These practices are shaped by cultural norms, values, and social contexts.	Shove, 2010; Shove et al., 2012; Hui et al., 2017
Socio-Spatial Justice	Equitable distribution of resources, opportunities, and benefits across different social groups within specific geographic areas.	Soja, 2009, 2010, Fainstein, 2009, 2010; Sen, 1979
Socio-Technical Landscapes	Complex interconnected systems that encompass both social and technical aspects. These landscapes involve the interaction between human behaviours, social structures, and technological elements within a specific context.	Geels, 2002
Socio-Technical Regimes	Stable and enduring arrangements that involve the interaction of social practices, institutional structures, and technological systems within a specific domain or sector. These regimes represent established patterns of how society and technology are organised, governed, and function together.	Geels, 2002
Soft Mobility	See Active Mobility, used interchangeably, originating probably from regions with different dominating languages.	
Solution	A response to a specific problem or several not implying that it necessarily solves the latter.	
Sustainability	Ability to meet the needs of the present without compromising the ability of future generations to meet their own needs.	WCED, 1987
Sustainability Transition	Deliberate and systematic shift from existing practices, systems, and behaviours toward more sustainable alternatives.	
Sustainable Development	Development of an area or territory following the definition of sustainability.	
Synthetic Populations	Artificial or simulated representations of real populations that are created for research, modelling, or simulation purposes.	Hörl and Balac, 2021
System of Systems	Complex arrangement or network of individual systems that work together to achieve a larger, integrated goal.	Forrester, 1969
System Transition	Significant and deliberate shift from one state or configuration of a system to another.	Geels, 2002
Territory	The term has various meanings across disciplines and languages. Elden highlights that 'conventional definitions of territory emphasize [sic] boundedness, identity, integrity, sovereignty and spatial coherence' (2010). Others, such as Raffestin, Foucault, or Lefebvre refer to it in different ways as container for/of power, generated from space through the actions of an actor who 'territorialises' space. Further, Delaney summarises the need for an inside and outside. This work makes few references to territory but instead to urban areas as smaller version thereof. Due to the ambivalent use of the term territory in French and English – leading to ample initial discussion – it is nevertheless included here as important underlying concept.	Author, based on Delaney, 2005; Elden, 2010; Raffestin, 1980; Foucault in Grbin, 2015; Lefebvre, 1991, Soja, 1989.
Transdisciplinarity	Approach that goes beyond traditional disciplinary boundaries to address complex problems by integrating knowledge, methods, and perspectives from multiple disciplines, as well as involving stakeholders from various sectors and communities.	Lawrence, 2010
Transit	Movement of people, goods, or information from one place to another, typically involving a mode of transportation.	
Transition	Transition from current to future state by addressing one or several problems of current state through specific solutions.	Rotmans and Loorbach, 2009
Transition Management	Strategic and systematic approach to guiding and facilitating significant changes within organisations, industries, or societies.	Rotmans and Loorbach, 2009
Transport(ation)	Movement of people, goods, or information from one location to another.	
Uncertainty	Lack of predictability or clarity about future outcomes, events, or conditions. It is a state of not knowing what will happen, often due to incomplete information, complexity, or randomness.	Courtney et al., 1997

TERM	DEFINITION	REFERENCE(S)
Urban	Urban can be used as adjective to describe elements within urban areas but also to larger socio-spatial phenomenon implying the agglomeration of people, resources, knowledge, cultural activities, and sometimes political power (cf. Territory). In its most abstract sense, the urban is understood as umbrella term to describe the spatialisation of human society.	
Urban Area	An urban area refers to both a population density (varying by context) and the existence of societal, cultural, economic, administrative functions. (cf. Functional Urban Area)	
Urban Mobility	Urban mobility refers to human, personal mobility within an urban area, including that of people within and in exchange with the outside. This integrates the larger definition of mobility as core ingredient of urban settlements by permitting the access of opportunity and thus economic development (cf. Bertraud, 2018).	Bertraud, 2018
Urban Mobility System (UMS)	An Urban Mobility System (UMS) describes the multiscale and multi-disciplinary complex adaptive socio-technical system that defines personal mobility taking place in the primarily continuous daily territories of the residents and users of an urban or metropolitan area. It is constituted of sub-systems, situated between urban and local scale, as well as social and technical elements. It changes through internal and external dynamics yet retains a continuously recognisable system state at all times.	
Visions	Visions are (usually) singular future visualisations that present a preferred state by a certain group. It overlaps often with normative scenarios.	Tanum et al., 2020
Weak Signals	Emerging trends or phenomena that might not be immediately evident but could have significant implications.	Ansoff, 1984; see Kaufmann and Ravalet, 2016, for application for mobility scenarios

AP.3: Information about publications

Several scientific publications have been created during the doctoral project. They are listed in Table 64. Some of them are used partially or in full in the dissertation (D), some are open access (OA) and linked directly, while one is provided in this appendix. The publications which are used within this dissertation contain modifications for clarity, continuity, and layout reasons, but do never communicate any contrary information to the published version. References to sections published elsewhere shall always be made to the original.

Table 64: Publications and information about their access (D = in Dissertation, OA = Open Access, A = in Appendix)

Article reference	D	OA	A
Gall, T., Vallet, F., and Yannou, B. (2022) How to visualise futures studies concepts: Revision of the futures cone. <i>Futures</i> , 143/103024. https://doi.org/10.1016/j.futures.2022.103024	4.2		
Gall, T., Hörl, S., Vallet, F., and Yannou, B. (2023) Integrating future trends and uncertainties in people-centred urban mobility design via data-driven personas. <i>European Transport Research Review</i> [forthcoming]	5.1.3		
Gall, T., Vallet, F., Ben Ammar, M. and Yannou, B. (2023) Designing solutions for uncertain futures: A checklist for choosing suitable scenarios. ICED23.	5.1.2	link	
Gall, T., Vallet, F., and Yannou, B. (2023) Comment concevoir des systèmes de mobilité urbaine pour les citoyens du futur ? Époque 07/2023.	4.3	link	
Gall, T., Chouaki, T., Vallet, F. and Yannou, B. (2023) Un cadre basé sur les scénarios du futur au service de la simulation multi-agents de la mobilité urbaine de demain. s.mart colloque.		link	
Vallet, F., Hörl, S., and Gall, T. (2022). Matching Synthetic Populations with Personas: A Test Application for Urban Mobility. <i>Proceedings of the Design Society</i> , 2, 1795-1804.		link	
Gall, T., Vallet, F., Douzou, S. and Yannou, B. (2021) Anticipate, Adjust, Adapt: Managing Sustainability Transitions through multiple Scenarios of Urban Mobility Futures. 49th European Transport Conference, online, Sept. 2021.			AP.3.1
Gall, T., Vallet, F., Douzou, S., and Yannou, B. (2021). Re-defining the System Boundaries of Human-Centred Design. <i>Proceedings of the Design Society</i> , pp. 2521-2530.	2.3.1	link	
Gall, T., Vallet, F. and Yannou, B. (2021) Co-Creating Sustainable Urban Futures: An initial Taxonomy of Methods and Tools. ISOCARP 56th World Planning Congress 'Post-Oil City – Planning for Urban Green Deals', Doha, Nov. 2021.		link	
Gall, T. (2021) Working with multiple Scenarios: Revising the Futures Cone. Conference paper, AESOP YA Conference 2021 in Tirana, Albania, March 2021.	2.2		
Gall, T., Vallet, F., Reyes, M., Hörl, S., Abdin, A., Chouaki, T., Puchinger, J. (2023) Sustainable Urban Mobility Futures: Transdisciplinary Challenges, Trends, and Pathways for Sustainability Transitions. London: Palgrave Macmillan/Springer. ISBN 978-3-031-45794-4 [to be published end of 2023]			
Gall, T. and Allam, Z. (2022) Strategic foresight and futures thinking in urban development: Framing planning perspectives and decolonising urban futures, p. 10-19. In: Peric, A., Permezel, M., Stott, M., and Woo, A. <i>Future Cities Series: Practical planning guidance for innovative, resilient and inclusive cities of the future: Discussion paper 1</i> . Nairobi/The Hague: UN-Habitat and ISOCARP.		link	

AP.3.1: Article on urban system modelling and their transitions

Title: Anticipate, adjust, adapt: Managing sustainability transitions through multiple scenarios of urban mobility futures

Abstract: Designing and managing system transitions towards sustainable urban futures are crucial to fulfilling the Paris Agreement and the United Nations (UN) Sustainable Development Goals (SDGs). However, the complexity and multidisciplinary nature of urban systems pose challenges to the holistic conceptualisation, design, and management of such transitions. Utilising complex system theory as the theoretical foundation, we apply transition concepts from Complex Adaptive Systems (CAS), Multi-Level Perspective (MLP), Social Practice Theory (SPT), and Future Scenario Methods (FSM) to explore the frameworks' potentials and shortcomings when applied to the urban mobility system transition (UMST) of Paris and its region Île-de-France (IDF) between 2001 and 2021.

Leading and supporting research questions are:

RQ1: To what extent can current transition frameworks represent the UMST?

RQ1a: What are the key transition drivers (TD) of Paris' UMST between 2001 and 2021?

RQ1b: What are the key transition frameworks that have been applied to UMST?

RQ1c: How adequately can these frameworks represent the UMST of Paris?

To answer these questions, we introduce the challenge and the underlying complex system theory, followed by the case study description. Afterwards, each framework is described, applied to the case, and discussed. This is followed by a literature-driven analysis and discussion of complements, commonalities, and mismatches between the frameworks. Finally, the initial outcomes are discussed, and a perspective for the next steps building on this preparatory work is drawn.

Key outcomes of the paper are:

- A descriptive case study of the UMST of Paris between 2001 and 2021;
- An interdisciplinary overview of UMST frameworks applied to the case study;
- A discussion of complementary, overlapping, and competing properties of the transition frameworks that will feed the next steps of the research towards the development of a holistic, heuristic transition framework for UMST.

INTRODUCTION

The planet is at the brink of an environmental abyss resulting from about two centuries of increasing resource depletion, environmental degradation, and widespread pollution (IPCC, 2014; IPCC, 2021). Mobility constitutes a significant accelerator to the complexity of the challenge – in particular urban mobility (UM) as an increasingly significant subsection due to continuously dominating global urbanisation (UN, 2015; UN-Habitat, 2016). Achieving a more sustainable future and averting imminent disasters requires an urgent and significant system transition. The importance does not solely lie within the environmental dimension of sustainability, but also in the social. Urban mobility defines the varying levels of access to opportunity and facilities within urban areas, of exposure to and integration within the society, and hence manifests diverse spatial inequalities (cf. ITF, 2021; FNAU, 2021; Karjalainen and Juhola, 2021). Approaching this challenge in an integrated and systematic approach is central to increase the potential of successful risk aversion (cf. Canitez, 2019; ITF,

2021; GIZ, 2014; Switzer, Bertolini, and Grin, 2013). However, three challenges are inherent: (1) Defining the extent and dimensions of the Urban Mobility System (UMS) at stake; (2) Working effectively towards highly uncertain futures; and (3) Analysing, enabling, and constructing sustainable transition pathways (cf. Hodson, Geels, and McMeekin, 2017). We aim to contribute with this paper to address these challenges – foremost the last – by providing a comparative analysis of the applicability of existing transition frameworks to UMST.

While these frameworks and their respective methods have found ample application in the field of UMS, we identified a gap in the harmonisation of their core elements, namely between CAS, MLP, SPT, and FSM. Thus, we describe the constituents, their potentials and limitations, and the added value of the joined application. The latter shall lead to a framework for conceptualising and managing transitions to sustainable UM futures, described further in the chapter on future work. We use the UMS of Paris as a case study to inform, test, and discuss the different transition frameworks. However, the analysis of the frameworks is meant to remain applicable to UMST in different settings.

The underlying challenge is described in the next chapter, supplemented by the theoretical foundation of urban areas and UM within complex system theory. The subsequent chapter describes the methodology, followed by the description of the UMST of Paris of the past two decades, focusing on a set of key Transition Drivers (TD). Based on the identified TD, we introduce the transition frameworks and their ability to represent the UMST of Paris. Finally, we discuss the different frameworks to crystallise overlaps, complements, and mismatches, and elaborate how these findings will feed the future work towards a holistic, heuristic UMST framework, followed by the conclusion.

DEFINING THE CHALLENGE

The global impact of the transport and mobility sector is significant. The greenhouse gas contributions of the transport sector alone are with 22% at the second place after heating, while 1.35 million people die on roadways annually (Climate Watch, 2020; CDC, 2020). In this context, UM – being both a principal contributor in a negative (e.g., air pollution, resource depletion) and positive manner (e.g., increasing access, accelerating poverty alleviation) – can be defined as a wicked problem. Wicked problems are problems that do not have defined solutions but are instead ‘re-solved – over and over again’ (Rittel and Webber, 1973, p. 160). Some of the characteristics include the impossibility of a ‘definitive formulation’, no defined end or solved state, no ‘true-or-false’ or ‘good-or-bad’, intrinsic uniqueness and interwovenness to other problems (Rittel and Weber, 1973, p. 161-165). Thus, UM calls simultaneously for urgent responses across scales and domains (ranging from, e.g., behavioural changes to technological improvements, locally and globally), while being on the other hand a problem impossible to define clearly and universally, even less ‘solve’ as such. Attempts of solving sub-problems or addressing specific challenges range from policymaking, planning and design disciplines, engineering, among others (e.g., GIZ, 2014; Ville de Paris, 2017; ITF, 2021). However, these multidisciplinary directions are frequently making use of different models, objective settings, and methods. This paper builds on the assumption that a more integrated and transdisciplinary approach would contribute to more effective responses to today’s challenges and thus holds the potential for more widespread and systemic transitions of UM (Hodson, Geels, and McMeekin, 2017; cf. Temenos et al., 2017; Whitmarsh, 2012). Complex system

theory is used as theoretical framing to address this, defined in the following sub-sections.

Cities as System-of-Systems (SoS) and Urban Mobility (UM) as Complex Adaptive System (CAS)

Most people already reside in cities, with at least 70% of the global population expected by 2050, doubling in numbers compared to 2015 (UN, 2018; UN-Habitat, 2016). Despite being a container for widespread socio-economic hardship, cities also are the most promising arenas for change and a sustainable future (UN, 2015; UN-Habitat, 2016). These cities, or, more precisely, Urban Areas (UA) – continuously urbanised areas without considering administrative boundaries – created and continue to create the most economical, cultural, and intellectual value and progress (UN-Habitat, 2016; Barber, 2013). Various elements are substantial to fulfil this function, primarily contained resources (e.g., natural primary/secondary, workforce, knowledge, capabilities, financial means, (e.g., military/legislative) power) (ibid.). Additionally, these resources must be easily accessible in exchange with the external world through commerce and trade and internally through moving, transporting, and exchanging within the UA’s boundaries. The human capital embedded in the population – in the past dominated by the manual labour force, today complemented or replaced by intellectual labour depending on the context – constitutes the primary resource. To bring these resources to optimal use, we can understand UM as the arteries, blood flow, and continuous exchange of diverse resources within a UA (among many others, incl. stationary components of UM). In this case, UM includes urban freight and logistic, yet the focus lies on UM of humans. Nevertheless, we consider logistics in the case of, e.g., connected activities (human mobility combined with logistics) or work-related trips.

When zooming out again, the concept of System-of-Systems (SoS) can be applied to UA. SoS, applied, for example, in engineering, computer, and management sciences, is defined as a large-scale collection of distributed, independent, complex systems (Kotov, 1999). Its, in this case, multi-scale sub-systems can be formed by either functional, geographical, administrative, or socio-cultural characteristics, as illustrated in Figure 103.

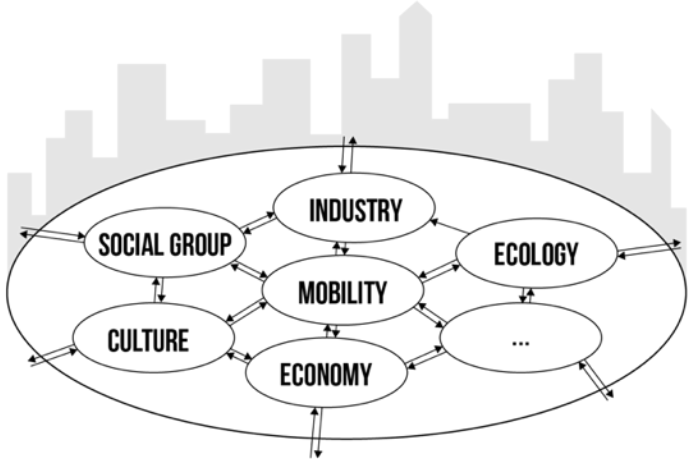


Figure 103: Cities / Urban Areas (UA) as System-of-Systems (SoS)

UM can be defined as one such sub-system, interconnected with the others yet with relatively clear boundaries. UA as SoS thus provides the container of UM. Its conceptual integration is paramount as it creates needs, requirements, and limitations for the UMS.

Urban Mobility (UM) as Complex Adaptive System (CAS)

Next, we define the herein applied conceptualisation of UMSs and its components and dynamics. Urban refers to qualities such as population/built density, multifunctionality, to economic and cultural activity, among others. We refer thus to a spatial context with a minimum level of urbanity, yet not necessarily coinciding with traditional administrative city boundaries. We utilise Mobility as the movement of people across modes of transport and purposes. Thus, UM defines movements of people within an urban area or leaving/entering/crossing it, regardless of trip purpose and means or modes. Thirdly, for System we distinguish between the complex system and general CAS properties described here, and the transition properties described later on.

Systems can be categorised into simple, complicated, complex, or chaotic systems. We assume that the UMSs can be defined as having an organised complexity, referring to a multitude of interrelated variables that, despite their complexity, have a minimum level of organisation and are neither random nor chaotic (cf. Rawforth, 2018, Brown et al., 2012). Further, the behaviours and changes of the interconnected system components (e.g., non-linearity, adaptation, self-organisation, and emergence, positive and negative feedback loops) provide a sound foundation to conceptualise UMST and the intertwined behaviour of its components (cf. Brown et al., 2012; Figure 104).

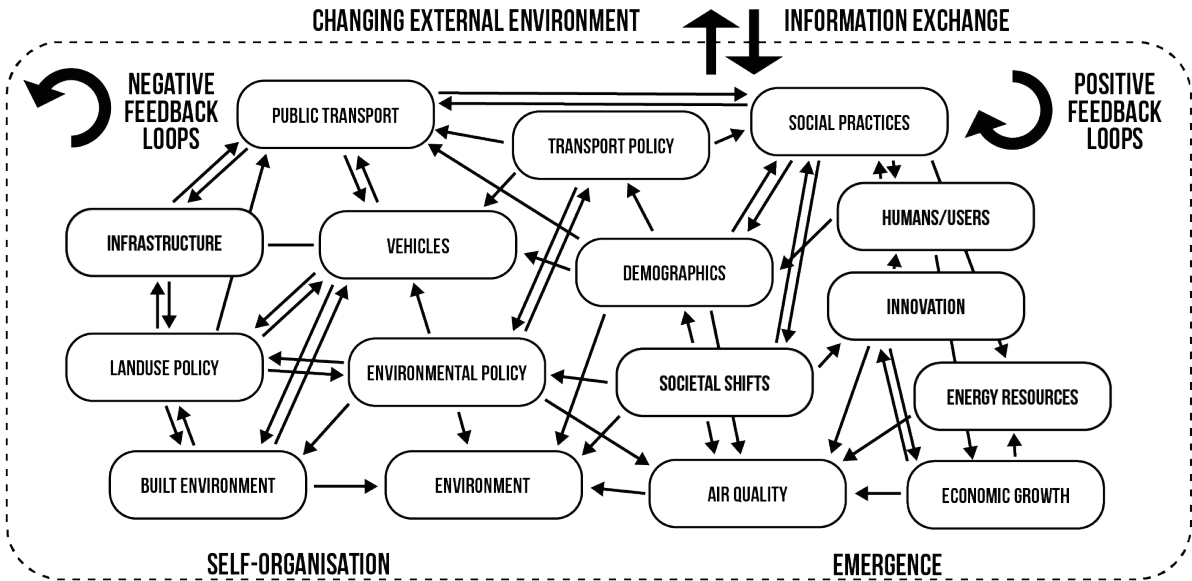


Figure 104: Urban Mobility (UM) as a Complex Adaptive System (CAS), with figurative Connections

Consequently, we cannot directly predict or fully control changes within the overall system. These may originate from a single or an interaction of several components. Each change might have secondary impacts through feedback loops or a more extensive system-wide adaptation or self-organisation. A practical example is the closure of a street which leads immediately to a rerouting of traffic. However, it may also reduce the overall traffic, shift to other modes of transport if they are becoming more competitive, increase traffic from remaining modes in the closed area, all the way to changing local air quality, noise pollution, property values, socio-economic residential composition – depending on how far and how significant the initial impact was.

METHODOLOGY

With the above as a theoretical foundation, we analyse and describe a case study of a significant UMST. Next, we review the literature on different transition frameworks and their application to UMS, supplemented by applying the frameworks to the case study UMST. Lastly, the frameworks are contrasted and discussed, combining the case study application findings and existing literature.

The first step, the case study, focuses on the City of Paris (hereafter Paris; pop. 2.1 M), which we must analyse in the context of the surrounding region Île-de-France (IDF), in which greater Paris has about 12.2 M inhabitants. Nevertheless, we can observe the most substantial UMST within Paris proper and thus chose it as the most suitable case. Further, we decided on a timeframe of twenty years from 2001 to 2021 because most today still impactful actions have been implemented within the last two decades, while 2001 also marked the beginning of a new political era, leading to increased initiatives in the field of UM. A list of Transition Drivers (TD) was compiled based on academic and grey literature occurrence. These are categorised through the Avoid-Shift-Improve (ASI) framework (Figure 105), which allows for prioritisation for policymakers and practitioners to foremost avoid harmful mobility, shift towards more sustainable practices next, and lastly improve existing modes of mobility, e.g., through electrification or improved fuel-efficiency (GIZ, 2014). Each TD is further complemented with additional data on the scale, timeframe (if applicable), and actors.

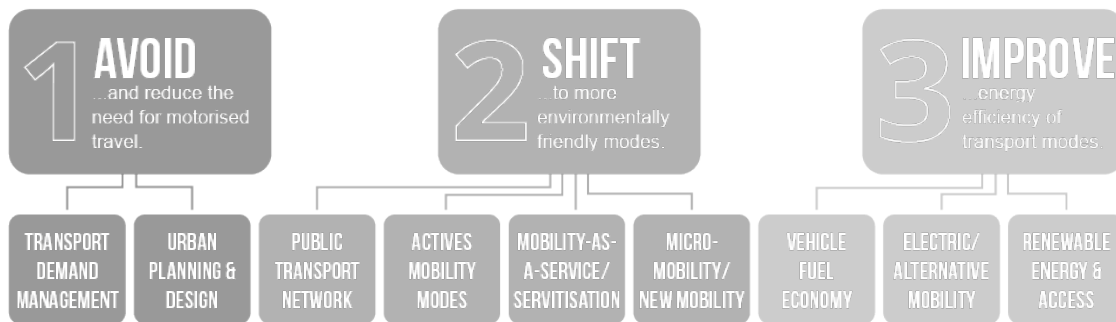


Figure 105: ASI-Framework (adapted GIZ, 2014)

The review of transition literature in the field of mobility and transportation fuels the understanding of how past and current transitions are and can be analysed within different disciplines and how possible and preferred transitions can be enabled and managed. Based on the identified literature, we created four categories (Table 65), from which the first, CAS, functions as an independent higher-level concept, while STS acts as an umbrella concept for the other three, namely MLP, SPT, and FSM. STS as the contextual concept is introduced in the following, while the four transition frameworks are described later.

Table 65: Reviewed Literature on Mobility/Transportation Transitions/Transformations

Framework	Selection of related literature
CAS	Brown et al., 2012; Transport Geography, 2021; Combes and van Nes, 2012
STS	MLP Hui, Schatzki, and Shove, 2017; Moradi and Vagnoni, 2018; Geels 2002, 2005, 2007, 2011; Whitmarsh, 2012; Canitez, 2019, Haxeltine, Whitmarsh, Bergman, Rotmans, Schilperoord, and Köhler, 2008, Köhler et al., 2009
	SPT Hui, Schatzki, and Shove, 2017; Bijker, Hughes, and Pinch, 2012, Shove, 2010, Shove et al., 2012; Williams, 2015; Bartiaux, 2013; Cass and Faulconbridge, 2016

FSM	Urry, 2016; Whitmarsh, and Nykvist, 2008; ITF, 2021; Auvinen and Tuominen, 2014; Bibri and Krogstie, 2019; Cascetta, 2014; Kaufmann and Ravalet, 2016; Martin, 2021; Miskolczi et al., 2021; Soria-Lara et al., 2021; Spickermann, Grienitz, and von der Gracht, 2014, Townsend, 2014
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Socio-Technical Systems (STS) are systems constituted by both technical and social elements. Technical does not refer to technology or pure technical artefacts but instead a broader definition of the more tangible and defined elements. It slowly arose as a concept since the Second World War to reconcile between the social, softer, and technical, harder fields of sciences; foremost to have a more integrated and holistic understanding of system dynamics and not ignore a significant – social – element due to the challenges such as applying traditional scientific methods to them (cf. Bijker, Hughes, and Pinch, 2012). Further, STS attempt to improve the ability to understand and describe the complex interactions between human, machines, and the environment (Baxter and Sommerville, 2011). Badham, Clegg, and Wall (2000, in Baxter and Sommerville, 2011) name five key characteristics STS:

1. *‘Systems should have interdependent parts.*
2. *Systems should adapt to and pursue goals in external environments.*
3. *Systems have an internal environment comprising separate but interdependent technical and social subsystems.*
4. *Systems have equifinality. In other words, systems goals can be achieved by more than one means. This implies that there are design choices to be made during system development.*
5. *System performance relies on the joint optimisation of the technical and social subsystems. Focusing on one of these systems to the exclusion of the other is likely to lead to degraded system performance and utility.’ (ibid., p. 5)*

STS provide the overall context of systemic analysis of urban environments and systems and simultaneously the theoretical foundation for three of the four transition frameworks (namely, MLP, SPT, and FSM).

THE URBAN MOBILITY SYSTEM TRANSITION (UMST) OF PARIS

Accelerated in recent years, Paris has taken an active role in the sustainability transition, exemplified in the successful re-election of current Mayor Anne Hidalgo in 2020 with a strong campaign focus on sustainability – building on the work of her predecessor Bertrand Delanoë (2001-2014). In this chapter, we provide an overview of the city and its enclosing region Île-de-France (IDF), followed by a description of the UMS, the impact of the UMST in the social and environmental dimension, and finally, a compilation of actions, policies, and plans that contribute to the UMST.

Paris is a global and national capital and the core of one of the most populous and powerful regions. The IDF is an international research and higher education centre, with over 1 M companies creating 6,4 million jobs (Paris Region, 2020). Further, the region hosts most international conferences and conventions, attracting 9.4 M visitors per year while being home to plenty of cultural amenities, such as 140 museums, 371 theatres, 307 cinemas, 4,000 monuments, 223 shopping centres, 23,000 restaurants and over 150,000 hotel beds (Paris Region, 2020). Being one of the most vital sectors of commerce and hospitality globally, the IDF provides a variety of potential trip origins, destinations, stops, and purposes. The impact of this leads to 108 M annual passengers of air traffic, 19 M train passengers, and a total of over 50 M tourists,

including 22.2 M foreign ones. The region's railway stations serve 1 M passengers on 3,550 trains per day, while Gare du Nord is the busiest European train station (Paris Region, 2020).

There are 2,753 km rail networks, 385 stations, and 6,200 regional trains every day within the region. At rush hour, over 650 trains run simultaneously (Paris Region, 2020). Additionally, a variety of self-service and free-floating bikes, cars and mopeds exist, which lead to 850,000 trips/day. Just the Velib itself, the public bike-sharing service of Paris since 2007, has about 16,000 bikes facilitating around 70,000 trips per day. Véligo Location, a long-term rental service (6 to 9 months) of electrically assisted bikes, provides another 10,000 bikes (Paris Region, 2020). Lastly, in Paris, around 18,000 e-scooters, 8,500 other bikes, and 4,000 scooters complement the mobility options, combined provided by Cityscoot (since 2016), COUP, GoBee Bike, Ofo, Obike (since 2017), MoBike, Lime, Bird, Bolt, Oribiky, Donkey Republic, Troopy and Tier (since 2018), and Ufo, Jump, Dott, VOI, B Mobility, Circ, Hive, and Wind (since 2019). Within 12 months, the free-floating scooters alone have been used for a total of 18.5 M trips, covering 41.4 M kilometres with an average trip distance of 2,2 km (APUR, 2020).

On the negative side, road infrastructure takes up 27% of space in urban areas, 57% thereof for cars (Héran and Ravalet, 2008) and various other resources in its lifecycle (Metabolic, 2019). The UMSs creates negative externalities for the society through lost productivity due to traffic, estimated at up to \$14bn per year in Paris alone (Cebr, 2014). Additionally, the local air pollution has reached significantly high levels with high numbers of associated deaths, while also noise pollution increased significantly throughout the city.

Paris' Urban Mobility System Transition (UMST)

A UMS is constantly changing and transitioning. Thus, it is not possible to delineate where one starts or end. We chose the period from 2001 until today due to the political cycles of Paris and the transition from a long period of conservative and car-dominated policymaking to a more progressive and environmental-oriented era. A few elements are crucial to return to the actions towards a more sustainable future. First, Paris is a strong actor in the international discourse around sustainability, being both the location and the namesake of the global Paris agreement (COP21, 2015) and a leading partner in city networks such as C40 or the Resilient City Network. Marked by those events, Paris pledges to reduce greenhouse gas emissions by 50% in 2030, 80% by 2050 and reach a state of carbon neutrality. Clean transport constitutes one of the four key areas to reach this goal, namely, reducing noise and air pollution and improving the quality of life of its residents through a greater variety of shared and active mobility (Ville de Paris, 2017, p. 9). To achieve this, Paris has pushed a range of policies over the last years, including greening the roofs, reducing parking lots in the city, subsidising the purchase of electric bicycles, or most recently, the concept of the 15-minute city. For the much-disputed ring road, various competitions and initiatives for transformative urban interventions were launched, focusing on the reimagination of the interface areas.

Further, ongoing campaigns for better cycling integration, changing traffic patterns during the pandemic, and resulting temporary cycle lanes provide a highly enabling environment for strengthening active modes. However, as activity maps show, the network remains disconnected. While some axes and paths along the Seine are dominant and continuous, others consist of discontinuous patches. An initiative by

the Collectif Vélo IDF (2020) conceptualised and lobbied heavily for a regional approach to continuous cycle lanes by proposing the RER V (velo), inspired by the public transport network, which has been integrated into the city’s bicycle strategy in 2021. Despite the transition, the overall modal share is compared to other countries still low, even more so for intermodal mobility. In the Netherlands, 40% of train commutes start or end by bike; in the IDF it is less than 2% (L’Institut Paris, 2020).

The 'Daily Mobility Barometer' (ADEME, 2016) adds the human perspective to France's current state of mobility. The data shows that 89% is worried about the environmental crisis, and 60% of the 18-24-year-olds believe that transport contributes 'a lot' to climate damage. Nearly 60% favour an end of fossil-fuelled vehicles by 2040. 38% of car drivers anticipate reducing their use in the next ten years, while 50% can imagine buying an electric vehicle, even if the price remains more expensive. One out of two survey participants thinks they could cycle parts or all of their trips if the infrastructure would allow, while 55% think they do not have a choice of how to move, a number rising to 85% in isolated communities. 77% of the same group also states that they have no access to public transport by foot. Two specific barriers are highlighted: For 50%, the cost is the primary barrier (on average 90 euros in cities and 141 euros in countryside per month for transport), while psychological barriers exist. The apprehension of taking public transport affects over 29% of the 18-24-year-olds and 25% of urban residents. Further, a disproportionately negative effect on more deprived households was identified. 25% of the group state that they do not leave their home more often than 2-3 times per week, commuting to the job constitutes the reason for 43% of all trips, while it is only 17% for the better-off groups (ADEME, 2016).

Moving on to an outlook of future impacts, the Grand Paris Express will add 200 km of automated lines and 68 new stations to the metro network, serving 2 M passengers per day (Société du Grand Paris, 2020, Paris Region, 2020). Additionally, the pandemic is assumed to lead to long-term changes in commuting patterns. A range of connected laws (as well as won lawsuits against the insufficient actions of the French government against climate change) will impact the UMST further. These include the preparatory law TECV (Transition Écologique et Croissance Verte) in 2015, and the law LOM (Orientation des Mobilités) in 2019, specifying a range of actions and quantifying, e.g., the number of mandatory bike parking at stations (FNAU, 2021). While the LOM will have a significant impact on Paris itself, the already ongoing progressively increasing city-specific policies (e.g., on car-free days, the Low Emission Zone, or reduction of parking spots) are supplemented with more radical changes like the reduction of the maximum speed to 30 km/h on all streets within Paris except for a few key axes. We compiled these and more Transition Drivers (TD) below (Table 66), categorised by the earlier introduced ASI framework.

Table 66: Compilation of Transition Drivers (TD) of UMS transition of Paris

	Transition Driver	Definition	Geogr. Scale*	Actors **	Reference s
AVOID	TDA1: Planning	Urban and regional planning, primarily to densify (incl. TOD) and strengthen multi-use areas.	S-XL	PU/IG	FNAU, 2021
	TDA2: National Projects	Projects of national interest that re-cluster existing functions (e.g., Paris-Saclay).	XS/XL	PU/SP / PR	fpaps.fr

	Transition Driver	Definition	Geogr. Scale*	Actors **	References
	TDA3: Métropole Paris	Governance restructuring to facilitate integrated planning across administrative scales in 2014.	M	PU/SP	metropolegrandparis.fr
	TDA4: Tele-Everything	Through COVID-19 accelerated provision of tele-working/-medical support, online-shopping, etc.	XS-XXL	ALL	
SHIFT	TDS1: LEZ	Low Emission Zones, initially introduced in 2015, limited progressively access of polluting vehicles.	S	PU	Ville de Paris, 2017, p. 143
	TDS2: Parking Policies	Integrated parking mngt., reducing overall number of parking spots, increasing pricing, etc.	S	PU	lez-france.fr
	TDS3: Speed Reduction	Speed reduction to 30 km/h on most streets from 30/08/21, with prior 63% public support.	S	PU/CS	paris.fr
	TDS4: Road Opening	Opening streets to active modes, e.g., Rue du Rivoli, restricting motorised traffic to taxi/bus.	XS/S	PU/CS	paris.fr
	TDS5: Car-free Trial	Mobilité360 by Mobilize (Renault Group), Blablacar, RATP, & Uber to make 1000 car-owners trial car-free life for a few months with incentives and vouchers for carsharing, etc.	M	PR/SP	media.renaultgroup.com
	TDS6: Veligo	E-Bike rental scheme by regional public transport agency, to trial them for maximum 9 months.	L	SP	veligo-location.fr
	TDS7: Car-Sharing	Various local and international car-sharing projects and platforms, e.g., Ubeeqo.	S-XL	PR	ubeeqo.fr
	TDS8: MaaS	Mobility-as-a-Service integration in transport apps, development of data standards, e.g., IDMF.	S-XXL	PU/SP / PR	iledefrance-mobilities.fr
	TDS9: Cargo Bikes	Cargo bikes for delivery, professional use, rental, shared between residents, e.g., Veligo.	XS-L	PR/SP	veligo-location.fr
	TDS10: Carpooling	Carpooling platforms, often integrated in other navigation apps, e.g., BlaBlaCar.	XS-XXL	PR/SP / CS	blablacar.fr
	TDS:11 Placemaking	Various interventions in public space, creating 'places' by providing areas to sit, meet, etc.	XS	PU/PR / CS	pps.org
	TDS12: Bike Lanes	Citywide initiative to improve existing bike lanes, create new ones, and make the temporary 'corona-pistes' permanent.	S-L	PU	paris.fr
	TDS13: Bike Parking	Plan to create 10,000 public bike parking.	S	PU/PR	paris.fr
	TDS14: GPE	Grand Paris Express, one of the largest global public transport projects, adding about 200 km of automatised metro lines throughout the region.	M/L	PU/SP / CS	societedugrandparis.fr
	TDS15: New Trams	Since 2006, trams returned to Paris after over 60 years, being currently expanded to 13 lines.	M/L	PU/SP	ratp.fr

	Transition Driver	Definition	Geogr. Scale*	Actors **	References
	TDS16: Velib	Fixed-station electric and normal bike sharing service established in 2007, with 20,000 bikes.	M	PU/SP	velib-metropole.fr
	TDS17: Micromobility	A variety of private entities provide various types of micromobility, including large/small e-scooters.	L-XXL	PR/SP / PU	APUR, 2020
	TDS18: Finan. Support	A variety of local, regional, and national financial incentives to repair or buy (electric) bikes.	XS-XL	PU/SP	paris.fr
	TDS19: RER Velo	A citizen-initiated project for a regional bike network, now supported by the Ville de Paris.	L	CS/PU	rev.fr
	TDS20: Bike Training	A variety of training courses and activities are organised on a regular basis, e.g., through fub.	XS-XL	CS/PU / PR	fub.fr
	TDS21: 15-Min.-City	Initiated by Carlos Moreno, the 15-Minute City became a key element of the urban development campaign of the mayor, aiming at ensuring that everyone can reach key functions within 15 min.	S	PU/AC	paris.fr
IMPROVE	TDI1: E.-Vehicles	Electric vehicles that eliminate/reduce the need for fossil fuels and reduce the air pollution.	XL-XXL	PR/IG/ PU/AC	n.A.
	TDI2: Charger Netw.	The dev. Of charging infrastructure to ensure that EVs can be widely charged, e.g., Belib.	XS-XL	PR/IG/ PU/AC	belib.paris
	TDI3: Fleet Renewal	Public transport operators heavily invest in fleet renewal to more sustainable alternatives, e.g., in 2021 to buy up to 800 electric busses for Paris.	S-L	SP/PU / PR	ratp.fr
	TDI4: Auton. Veh.	Autonomous vehicles are developed to improve public transport access in under-served areas.	XS	PR/IG/ PU/AC	n.A.
	TDI5: Efficiency Impr.	Fuel efficiency of vehicles is improved through lightweight construction, e.g., Renault Twizy.	XXL	PR/IG/ PU/AC	renault.fr

* XS = Local, S = Citywide, M = Metropolis, L = Region, XL = National, XXL = International

** PR = Private Actors, SP = Semi-Public Entities (e.g., Public Transport Providers), PU = Public, CS = Civil Society, IG = Intergovernmental Entities. AC = Academia

The UMS is a vibrant field and topic, and it is impossible to list all possible TD. However, we attempt to provide a representative list spanning domains, scales, and actors. In the larger picture, of course, not all have or have had the same impact. Actions that did not have the anticipated impact were purposefully left out as they are assumed not to have influenced the UMST significantly would, however, be equally as interesting to study further.

Transition Impacts

The described UMST has led to an overall reduction of air and noise pollution and decreased car traffic. Nevertheless, it is difficult to fully quantify the impact as many environmental impacts are not on the local but regional or global scale and impacting local systems elsewhere (e.g., through production, extraction of raw materials). Furthermore, positive secondary impacts can range from health to increased social

exchange, increased lifespan, and others. As these are more difficult to measure, we focus in this scope on the distinctly quantifiable impacts.

Between 2001 and 2018 (latest data), the number of daily trips in IDF increased in general. However, most of the growth comes from walking and public transport (and a bit cycling), while the proportion of car trips decreased (APUR, 2021, p. 9). While car trips by person remained stable in the outer areas of the IDF, these trips have significantly and continuously decreased for Paris proper and the inner area around it (ibid., p. 13). At the same time, the walking trips per person/day increased by over one third in the same period (ibid., p. 22). The same trend exists for cycling, while the cycling infrastructure within Paris grew from 256 km in 2001 to 1,085 km in 2020 (ibid., p. 42). At the same time, air quality has increased overall yet is regularly at critical levels, primarily for those close to principal infrastructure arteries (Paris, 2021).

DESCRIPTION AND APPLICATION OF FRAMEWORKS

This chapter describes each of the four transition frameworks and their respective application to UMST. Further, the in Ch. 4 described case of the UMST of Paris is contrasted with each framework. Despite having different components and structures, each has relevant attributes, such as the CAS behaviours and adaptation properties, the transitions within the MLP, the possible transition of social practices according to SPT, and finally transitions as conceptualised and stipulated through future scenarios.

Complex Adaptive Systems (CAS)

Additional to the overall properties of CAS, specific behaviours exist, e.g., lock-ins, barriers, resilience, robustness, elasticity (cf. Rotmans and Loorbach, 2009), and those mentioned in table 3 in the transport context. The key characteristics of CAS are the internal dynamics within system components or between them that can be, for example, self-organisation, emergence, or adaptation, leading to system changes depending on the existing rules (cf. Brown et al., 2012, for infrastructure example, Combes and van Nes, 2012, for sub-system analysis of CAS for IDF).

Table 67: Behaviours of Complex Transport System (Transport Geography, 2021, adapted from OECD, 2009. Applications of Complexity Science for Public Policy: New Tools for Finding Unanticipated Consequences and Unrealised Opportunities, Global Science Forum)

Adaptability (Competition)	Adaptation to the actions of other components. Adaptation to social, economic and technological changes.
Self-Organisation (Routing)	Autonomous adaptation to changing conditions as a result of the adaptability of the individual components.
Stability (Land Use)	A recognisable dynamic state of a system that may continuously reappear.
Cumulative (Congestion)	Changes in one property or component may have a disproportionately large effect on another property or component.
Transition (Containerisation)	A system’s behaviour may change radically, and sometimes irreversibly, when a tipping point is reached.

In the case of Paris, a variety of possible (sub-)system transitions can be conceptualised as CAS as it has no inherent limitation on the domain or field. For example, the development of electric mobility is constituted from multiple components, such as the European, national, and local regulation, the technologies, e.g., developed in Paris-based OEMs Group Renault and Group Stellantis (incl. Peugeot), the charging infrastructure (combined public and private), the energy

market, the business environment for innovation, the interest from the population, and success (or failures) of pilot projects. Each of these components has an individual behaviour that can lead to system changes and interacts with the others. Small changes within individual components might not lead to significant changes and result in a certain system resilience, while substantial developments of intertwined, complementary changes lead to system-wide transitions.

Multi-Level Perspective (MLP)

Secondly, the MLP conceptualises socio-technical transitions by proposing three horizontal layers. On the top is the socio-technical landscape, which is the environment in which everything else exists. If the landscape changes, it puts pressure on the lower level and might, in response, be impacted by it as well. At the centre is the socio-technical regime. This regime represents a system of interconnected elements, such as technological, market, or societal dimensions. Geels (2011) refers to the socio-technical regime as ‘dynamically stable’, which can be interrupted by landscape pressures, leading to temporary instability. On the smallest scale are technological niches (cf. emerging issues, weak signals, nudges) that can enter the socio-technical regime during moments of instability, leading to an adapted socio-technical regime, which influences the larger socio-technical landscape (Figure 106).

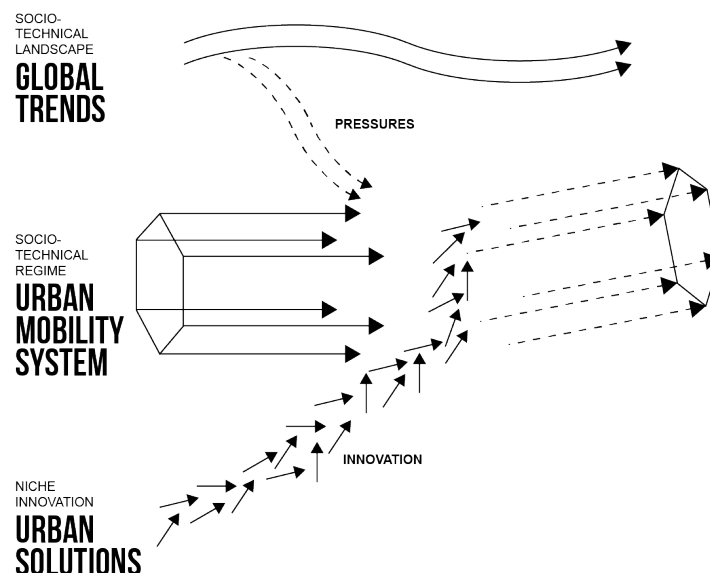


Figure 106: Multi-Level Perspective (MLP) Transition Theory (adapted from Geels, 2011)

Switzer et al. (2013), among others, have applied the transition theory in the context of mobility. In their case, they apply the conceptualisation to identify barriers and system inertia of mobility and the conceptualisation of mobility systems. Moradi and Vagnoni (2018) further extend the application of transition theory and review and compile a list of possible transition pathways, landscape dynamics, and mobility niches with a geographical focus on Italy. Regardless of the focus, many of them should be applicable elsewhere. The authors name and compare various transition pathways such as endogenous renewal, re-orientation of trajectories, emergent transformation, positive transition, technological substitution, reconfiguration, transformation, de-alignment and re-alignment, market rules, action-reaction, central control, thousand flowers, auto-city (reconfiguration), eco-city (de-alignment and re-alignment, and electricity (substitution). Further, they identified possible landscape pressures as economic growth and crisis, industrial development strategies, customer preferences (e.g., speed, convenience, time-saving), demographic factors,

mobility demand, government strategies, cultural values (ownership, privacy, choice, progress, wealth), land use and urban structure, the resistance of decision-makers, open and general goals and regulations for clean energy, increasing demand for mobility, resources and infrastructure, funds for infrastructure development, as well as technological strength. Further, they differentiate between the private car-based regime, public transport regime, and non-motorised transport regime, each with respective lock-in forces as well as cracks and tensions (destabilising forces). Their application of transition theory to the mobility context showcases the range of dynamics and trends, possible conceptualisations of mobility regimes, and the systemic complexity and the consequential need for an appropriate approach (Moradi and Vagnoni, 2018).

Further applications of the MLP were conducted by one of the leading authors in the transportation and mobility field, namely on the transition from horse carriages to automobiles (Geels, 2005) and of Dutch highways (Geels, 2007). Canitez (2019) provides a comprehensive MLP perspective on holistic UMST in megacities with high relevance for the case of Paris, while Whitmarsh (2012) provides a detailed analysis of the adequacy of MLP for transport and mobility transitions. Finally, Köhler et al. (2009) applied the MLP to sustainable mobility primarily quantitatively. While each application varies in scope, it shows the wide range of applicability and the potential for at least adequate partial representation and modelling of UMST using the MLP.

Social Practices Theory (SPT)

Building on the same STS body of literature (cf. Bijker, Hughes, and Pinch, 2012), social practices are another perspective on transitions. At its core lies the understanding that practices are emerging, formed, and altered continuously as a societal process, constituted by three key components (Figure 107). Materials provide the (mostly) physical means for a practice to exist. Without a bike, there is no cycling.

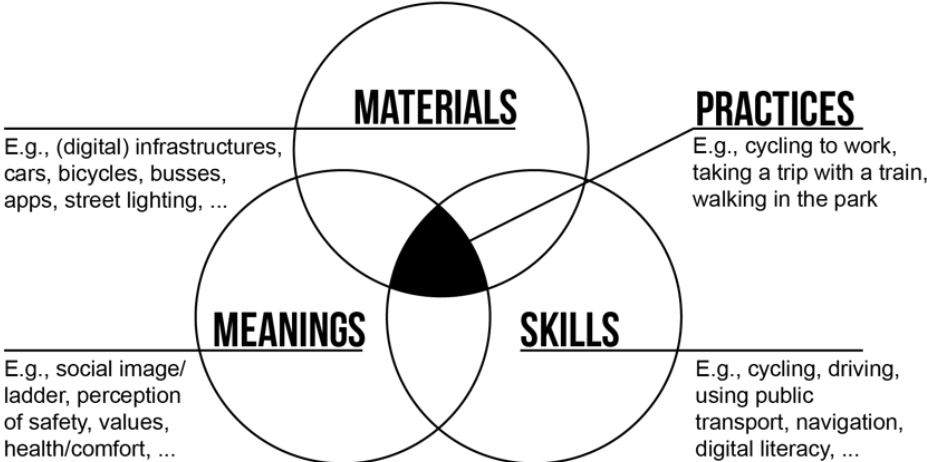


Figure 107: Three Dimensions of Social Practices with Mobility Examples

The second element is meanings, referring to perceptions, values, and a social group’s understanding of a particular practice. To remain with the cycling example, in many countries, cycling is seen as either a poor person’s means of transport or a solely exercising activity, both contradicting cycling for daily uses. Lastly, there are skills, such as riding and repairing a bike or operating it safely in traffic (cf. Foreword, Introduction, and ‘The Social Construction of Facts and Artifacts’ in Bijker, Hughes, and Pinch, 2012 for an extended SPT perspective on cycling). The social practice of ‘car driving’ is discussed in detail by Shove, Pantzar, and Watson (2012).

The previous examples are particular to a definite practice. However, studies with a broader and more integrated perspective exist, e.g., by looking at local transport planning in England (Williams, 2015), an intertwined process of several social practices' transitions to a 'life with no car in a system of automobility' (Bartiaux, 2013), or the transition of different commuting practices (Cass and Faulconbridge, 2016). Despite the range of practices, in contrast to MLP, a clear focus on smaller, more independent dynamics instead of external factors becomes evident.

In Paris, a suitable example of policy and product-service provision is the earlier mentioned Veligo e-bike rental scheme, supported by the public sector and managed by the mobility entity Île-de-France Mobilités. It provides the key 'material' in the shape of electric bikes, contributes to reconfiguring meanings through, e.g., publicity campaigns, and develops skills through extensive service offers. However, the rental period is restricted to six (plus three) months, thus not targeting an overall service provision such as Velib but instead the provision of a short-term trial of new practices (changing meanings and skills), with the subsequent (financial) incentive to buy a personal electric bike.

Future Scenarios Method (FSM)

The last framework stems from the field of futures studies that generally understands the future as a possibility space of multiple possible, plausible, or preferred futures also referred to as scenarios (cf. Dator, 2019; Inayatullah, 2013). First, there are different endogenous and exogenous forces comparable to systems thinking. Particularities are the core understanding of transition pathways as multiple (or infinite), wild cards as high-impact, high-uncertainty events, as well as backcasting from visions or preferred/normative futures backwards in time by identifying what actions would possibly lead to a specific future (Bibri and Krogstie, 2019), or transcendence between multiple possible futures (cf. Inayatullah, 2013, applied in mobility context in ITF, 2021). A last relevant component particular to futures studies is the notion of decolonising futures, referring to the planning for possible futures in a way that allows the future population to define and plan their reality according to their own state of knowledge, needs, and preferences.

The examples from UMST and FSM are too extensive to cover fully. Urry (2016, pp. 125-155), Kaufmann and Ravalet (2016), and Townsend (2014) provide the most holistic overviews, while Auvinen and Tuominen (2014) provide one of the most comprehensive academic reviews, supplemented by the International Transport Forum (ITF, 2021) which recently published an extensive guide of using FSM for UMS. SPREAD (2012) analysed sustainable lifestyles at the interface of MLP and multiple futures, while Cascetta (2014) provides a holistic urban system perspective. Miskolczi et al. (2021) have created the most exhaustive systematic literature review of mobility scenarios until 2030, expanded by Martin (2021) for autonomous futures with a specific MLP perspective. Lastly, Spickermann, Grienity, and von der Gracht (2013) and Soria-Lara et al. (2021) provide mobility-specific method descriptions, while Whitmarsh and Nykvist, 2008, propose quantitative sustainability assessment of possible mobility futures with underlying MLP and transition conceptualisation. In the case of Paris, the most specific examples are the futures of Paris itself (Ville de Paris, 2017), painting key future visions for mobility, and the 15-Minute City as a clear vision for the anticipated future of streets, public space, and UM.

DISCUSSION AND FUTURE WORK

As a general disclaimer, many different domains, applications, and conceptual framings make it impossible to combine all of them without losing at least some advantage or level of depth of the components. Nevertheless, the advantages of facilitating communication across disciplines, focusing on the similarities, and resulting in a heuristic framework that has a more holistic scope are deemed utile enough to justify this combination. This section summarises the previous comparison (Table 68), discusses the frameworks' general and specific comparative characteristics, and outlines the scope of anticipated future work.

Table 68: Primary consideration of each TD in the four transition frameworks

Transition drivers (TD)	CAS	MLP	SPT	FSM	Transition drivers (TD)	CAS	MLP	SPT	FSM
TDA1: Planning	X	X		X	TDS12: Bike lanes	X	X	X	X
TDA2: National projects	X	X		X	TDS13: Bike parking	X	X	X	X
TDA3: Métropole Paris				X	TDS14: GPE		X	X	X
TDA4: Tele-everything		X	X	X	TDS15: New trams	X	X	X	X
TDS1: LEZ		X		X	TDS16: Velib		X	X	X
TDS2: Parking policies		X		X	TDS17: Micromobility	X	X	X	X
TDS3: Speed reduction				X	TDS18: Finan. Support			X	X
TDS4: Road opening			X	X	TDS19: RER velo			X	X
TDS5: Car-free trial			X		TDS20: Bike training			X	
TDS6: Veligo	X	X	X		TDS21: 15-min.-city				X
TDS7: Car-sharing	X	X	X	X	TDI1: E.-vehicles	X	X	X	X
TDS8: MaaS	X	X	X	X	TDI2: Charger netw.	X	X	X	X
TDS9: Cargo bikes	X	X	X	X	TDI3: Fleet renewal	X	X	X	X
TDS10: Carpooling			X	X	TDI4: Auton. Veh.	X	X		X
TDS11: Placemaking			X	X	TDI5: Efficiency impr.	X	X		X

Discussion

The starting point is to return to characteristics of wicked problems: No simple solution exists. Thus, when talking about transitions, it is not assumed that it is a transition to a defined state but rather a development in a particular direction that can be linked to specific sub-goals. For example, the UMS shall move in a more sustainable and human-centred direction and contribute to remaining within 1.5-degree Celsius global temperature increase compared to pre-industrialisation levels and ensure that everyone has access to safe transportation. While these are clearly defined and quantifiable, no specific state of the global UMS is linked to achieving them. Therefore, no defined pathway or solution approach can be provided, mainly in the long term. Instead – as pointed out in the section on futures scenarios – possible positive and preferred pathways are outlined that are currently assumed to contribute to the overall goals but leave room for adaptation and adjustment over time with increasing knowledge or changing context or goal settings.

The second element is the variety of approaches that can be pursued to achieve transitions. For example, policies can be broadly grouped in ‘Carrots, Stick and Sermons (Bemelmans-Videc et al. 1998). Carrots describe enabling policies that provide either financial, material, or other incentives to do or not do a certain activity. Sticks are the opposite, referring to punitive schemes, e.g., additional taxes, penalties, or increasing fees. Lastly, ‘sermon’ refers to any convincing, moral, or preaching approach that conveys a specific value-driven message to impact behaviours or practices.

Further, a disparity exists between approaches and theories that focus on individuals and society or its subgroups. Individual theories, coming from behavioural studies, can build on, e.g., rational decision-making (cf. Simon, 1955). The focus lies on the ability of an individual to make informed decisions within their bounded rationality. On the other side are more social and group dynamics theories, such as the SPT, focusing on the co-production of practices and behaviours of a group or society. Despite their frequently dichotomous character in discussions, the ambition of this paper is not to fuel this debate but to attempt to combine relevant critical elements of transition theories to fuel an applicable framework instead. Thus, this controversy is only considered if it leads to conceptual disagreements (as discussed below).

The last challenge – and possibly the most common one in policy debates – is the transition-specific chicken and egg problem: Which part needs to be there first and causes the other? For example, do we need more bus lines to get more people to use the bus or do more people need to use the bus to justify more bus lines? As the preceding paragraph, this is a very relevant yet not necessarily binary component of transitions. In most applied cases – opposed to theoretical observations – it is not either-or. Even if specific actors usually follow a relatively rigid framing, the complex reality leads to overlapping actions of various types, which – combined – are achieving transitions (see exemplary transition behaviour visualised in Figure 108). Lastly, regardless of focus on individuals or groups, not every policy or intervention works for everyone or everywhere, or as intended (Rawforth, 2018).

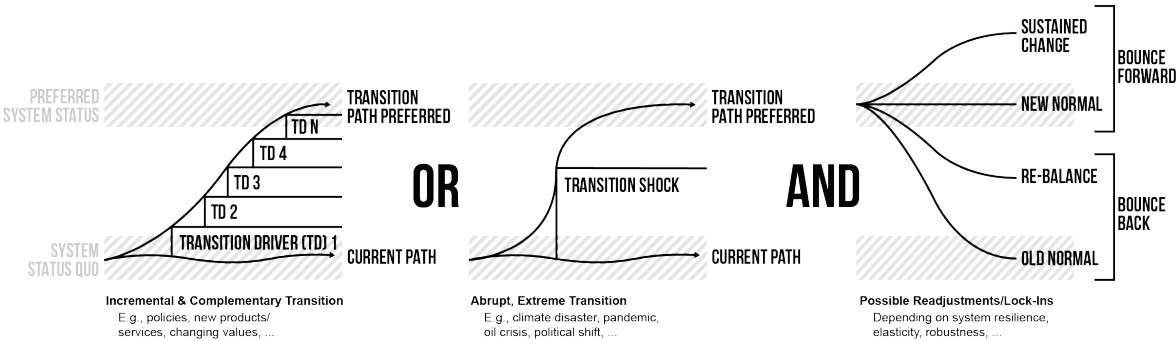


Figure 108: Possible Transitions through Exogenous Impacts

Next, we address (mis)matches specific to the presented concepts, synthesised in Table 69. The focus lies on behaviours of socio-technical regimes within the MLP and the utilised transition behaviours of CAS and the often-discussed disagreements between MLP and SPT and possible ways of reconciliation (see Geels, 2011; Hargreaves et al., 2012 for detailed discussions of the latter).

Table 69: Synthesis of complementary and contrasting Characteristics of presented Frameworks

FW 1	FW 2	Complementary Characteristics	Contrasting Characteristics
CAS	MLP	Socio-technical regimes within MLP are described with similar characteristics as CAS. System instability and resilience caused through pressures within MLP overlap with CAS reconfigurations.	MLP separates landscape, regime, and niche level, while CAS attempt to encompass all core elements without necessary scale differentiation. CAS focuses on internal forces, MLP on external.
	SPT	Properties of social practices comparable to CAS, e.g., emergence, disappearance, persistence (Shove, Pantzar, and Watson, 2012, pp. 57-62)	None, mostly different scope/goal.
	FSM	FSM focus on process towards future instead of system that transitions, thus, no contradiction/complement.	None.
MLP	SPT	<p>‘...stable/routinized practices can be seen as “regimes”, whereas emerging fluid practices can be seen as “niche”...’ (Geels, 2011, p. 37).</p> <p>‘...fully understanding transitions demands simultaneous investigation along three distinct but connected lines of enquiry: i) transitions in regimes as they occur through interactions between niches, regimes and landscapes – the vertical circle; ii) transitions in practices as they occur through change and continuity in different circuits of reproduction – the horizontal circle; and iii) how regimes and practices interconnect with and bump into one another in the course of transitions processes – the points of intersection’ (Hargreaves et al., 2012, p. 10).</p> <p>Possible approach to assign practices to multiple agents within regime (cf. Köhler et al., 2009)</p>	MLP focuses on the vertical impact between landscape, regime, and niche while SPT focuses on the changes within social practices, thus rather being on the horizontal layer (Hargreaves et al., 2012, pp. 6-7). Practices deny importance to external forces (cf. Geels, 2011, p. 37).
	FSM	MLP and FSM are highly compatible, both with global trends/pressures, an effected, moving system/regime, and niche developments, solutions, innovations, impacting and reconfiguring the pathway.	None.
SPT	FSM	SPT and FSM focus traditionally on different, yet complementary phenomena. FSM are often overlooking social practices.	None.

Future Work

This paper provides the basis for the larger ambition to develop a holistic, heuristic framework for UMST to support the analysis of past and present transitions and enable and construct future transitions. Therefore, the following steps include validating the described analysis and hypotheses, reconciliation of discussed frameworks, subsequent modelling of a holistic framework, and finally, the validation through experimentation in a second, localised UMS context. Furthermore, work is needed on an in-depth compilation and analysis of TD in UMS. This can build on the

initial Paris case, extended with generic, other local, or unsuccessful examples. Secondly, a stronger focus on possible system dynamics of UMST is needed (cf. Grin, Rotmans, and Schot, 2011). This can build on existing dynamics (Table 70) and requires additional research on possible triggers, nudges, or otherwise suitable planned interventions to impact the UMST.

Table 70: Figurative List of Transition Dynamics by Framework

CAS behaviours	MLP Transition Patterns	SPT Dynamics (Shove, Pantzar, and Watson, 2012)	Transitional Forces or Behaviours in FSM
Adaptation, self-Organisation, stabilisation, cumulation, transition (adapted from Transport Geography, 2021)	Transformation	Making and breaking links	Emergence, transcendence (Inayatullah, 2013)
Emergence, Dissipative structures, diversity & coherence, new attractors, punctuated equilibriums, coevolution, Variation & selection, Interactions, feedbacks Patterns, mechanisms (Rotmans and Loorbach, 2009, p. 191)	De-alignment and re-alignment	Emergence, disappearance, persistence	Continued growth, collapse, steady state, transformation (Dator, 2019)
	Technological substitution	Recruitment, defection, reproduction	Wild Card events
	Reconfiguration (Haxeltine et al., 2008)	Bundling, collaboration, competition	
		Selection, integration	

Additionally, many different transitions domains exist that have not been focused on further in this paper, e.g., policymaking, taxation, land use planning, local planning, or product and service design. Are transition behaviours comparable between them? Does the framework need to be adapted, or should they be applicable for each?

CONCLUSION

This paper is a working status depiction of the attempt to reconcile prevailing transition frameworks across disciplines, building on extensive similarities and possible advantages. Nevertheless, such frameworks remain primarily heuristic and – operating within the complex system field – can never be seen as correct and final, but rather as the most suitable framework for a particular purpose.

Also, understanding, enabling, and impacting transitions are three different activities. This paper primarily focuses on the latter while partially utilising concepts that have been primarily used for the first (e.g., SPT). Nevertheless, we argue that this paper provides the basis for a more holistic and interdisciplinary framework that can assist in the interpretation of transitions and their dynamics, and partially translate between different theories and fields and contribute to a more integrated approach towards transitions, and thus the work towards more sustainable urban futures.

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AP.4: Author's Curriculum Vitae

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Education

- 2019 Master of Science Architecture
Technical University of Braunschweig, Germany
- 2018 Master of Science Urban Management and Development
Institute for Housing and Urban Development Studies, Erasmus
University Rotterdam, Netherlands
- 2015 Bachelor of Science Architecture+
Technical University of Braunschweig, Germany

Research stays / visits (selection)

- 2022 American University of Cairo, Egypt
- 2018 Kampala, Uganda; Kigali, Rwanda; Mombasa/Nairobi, Kenya
- 2018 Addis Ababa, Ethiopia (Alfred Herrhausen travel grant)
- 2017 São Paulo/Campinas/Rio de Janeiro, Brazil
- 2013 College of Architecture and Urban Planning (CAUP)
Tongji University Shanghai, People's Republic of China

Positions (selection)

- 2023-2024 Carlo Schmid Fellow, Climate Change and Disaster Risk Management
Unit for South Asia, World Bank, New Delhi, India
- 2020-2023 Researcher, Anthropolis Chair, IRT SystemX, France
- 2022-2023 Research Fellow, Transport for Cairo, Egypt
- 2018-2020 Researcher, ISOCARP Institute – Centre for Urban Excellence
International Society of City and Regional Planners (ISOCARP)
The Hague, The Netherlands
- 2012-2019 Research assistant (various institutes), Technical University of
Braunschweig, Germany

Teaching / Supervision

- 2023 Bachelor thesis of Julia Godoy: 'The Urban Mobility Board Game'
- 2021-2022 Memoire thématique of Malek Ben Ammar: 'Scenario assessment'
- 2021-2023 Design Science, CentraleSupélec, University Paris-Saclay, France
- 2022 Plans and projects in Europe, Institut Français d'Urbanisme Université
Gustave Eiffel, France
- 2021 Storytelling with Urban Mobility Data, TU Munich, Germany
- 2018-2019 Geographic Information Systems
Institute for Sustainable Urbanism (ISU), Germany

Memberships (selection)

- 2023 French-German Forum on Sustainable Urban Development
- 2022-today Urban AI (Emerging Leader 2022)
- 2016-today International Society of City and Regional Planners (ISOCARP)
- 2015-today Young Academics Network of the Association of European Schools of Planning (AESOP), Coordination team member 2021-2023

Events (selection)

- 2023 ICED23, 24th International Conference on Engineering Design
24-28 July 2023, Bordeaux, France
- 12^e Colloque EPIQUE, 4-7 July 2023, Paris, France
- 5th CIRED International Summer School in Economic modelling of Environment, Energy and Climate, 19-23 June 2023, Paris, France
- Colloque national S.mart, 4-6 April 2023, Carry le Rouet, France
- 17th AESOP Young Academics Conference, 28-31 March 2023, Antwerp, Belgium
- 2022 Early-Career Workshop in Urban Studies, 23-25 November 2022, Lisbon, Portugal
- United Nations Climate Change Conference or Conference of the Parties of the UNFCCC (COP27), 6-12 November 2022, Sharm El Sheikh, Egypt
- 17th International Design Conference Design2022, 23-26 May 2022, online/Cavtat, Croatia
- Institut Pascal 'Urban Mobility 2', 16 May-3 June 2022, France
- 16th AESOP Young Academics Conference, 5-8 April 2022, Istanbul, Turkey
- 2021 57th ISOCARP World Planning Congress, 8-11 Nov. 2021, Doha, Qatar
- 49th European Transport Conference (ETC 2021), 7-15 September, 2021, online.
- ICED21, 23th International Conference on Engineering Design 16-20 August 2023, online/Göteborg, Sweden
- Third Annual Grand Rendezvous of the Robomobile Life Future Workshop, 19 May 2021, online, France
- 15th AESOP Young Academics Conference, 29 March-2 April 2021, online/Tirana, Albania
- Anthropolis Chair Colloquium, 25-26 March 2021, online/Gif-sur-Yvette, France

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