Mobility Design

Shaping Future Mobility

Volume 2: Research

Kai Vöckler, Peter Eckart, Martin Knöll, Martin Lanzendorf (eds.)

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Introduction

Mobility Design

Research on the Design of Climate-Friendly and Sustainable Mobility

Kai Vöckler, Martin Knöll, Martin Lanzendorf, Peter Eckart, Stefan Göbel, Petra Schäfer, Annette Rudolph-Cleff, and Ralf Steinmetz

Climate change and resource scarcity are making it all the more urgent to find new solutions for mobility. This is becoming particularly evident against the background of the high level of environmental pollution caused by traffic. The introduction to this publication therefore outlines how new, climate-friendly mobility can be achieved and how transdisciplinary research can contribute to this goal. Consequently, mobility design is defined as a transdisciplinary task—an understanding developed by the authors, who are partners in a joint research project.[01] The focus here is how design research can contribute to the development of multimodal, environmentally friendly mobility, in particular to redesigning mobility systems in a way that is oriented toward people and their needs. This publication presents the results of this research project, which was carried out in various constellations also involving practitioners. Included as well are contributions by internationally renowned mobility researchers, who share their expertise on distinct areas of future-oriented mobility design. Thus, the already existing first volume of the Offenbach publication series on mobility design, with its focus on design practice (Eckart and Vöckler 2022), is here complemented by scientific findings and the methods of future mobility design. Together, the two perspectives aim to add the dimension of user-centered mobility design to current discussions about the transformation of existing transportation systems. Above all, we would like to thank our guest authors who have supported this project with their expertise.

The Impact of Traffic on People and the Environment

Transportation plays a key role in society's transition toward a sustainable way of living. This particularly concerns the environmental impact caused by carbon dioxide emissions, which must be drastically reduced. Motorized mobility in cities is expected to double worldwide between 2015 and 2050, according to estimates by the Organization for Economic Co-operation and Development (OECD) (ITF 2017). Road-based transport, however, has so far been unable to reduce its share of greenhouse gas emissions despite all the technological innovations in motor vehicle power transmission and exhaust technology (see for example the data on developments in the European Union; destatis 2021). Additionally, air pollutants are not the only environmental problems caused by car-based transportation; road infrastructure seals off soil, and traffic contributes to noise pollution (UBA 2021).

Millions are on the road every day, and often alone in their own cars—in Germany, a passenger car is occupied by around 1.5 people, and in commuter and commercial traffic the figure is as low as 1.1 and 1.2 people (FIS 2019). The private car dominates traffic, takes up more and more space, marginalizes other road users, and puts a strain on people and the environment. This leads to considerable problems, especially in densely populated urban centers, and highlights a socially unjust use of space. In German metropolitan areas, about 50 percent of the parking spaces designated for cars are in public spaces, even though only 58 percent of households have one (or more) cars (Nobis and Kuhnimhof 2018: 35).[02] The other 42 percent, the car-free households, have to contend with the fact that the limited public space available is taken up by automobile use. In short, the question for these urban centers is how to achieve an improvement in the living and amenity quality that benefits all residents. The congestion caused by

01 The research project »Infrastruktur—Design—Gesellschaft« (2018 to 2021) was funded by the Landes-Offensive zur Entwicklung wissenschaftlich-ökonomischer Exzellenz (LOEWE) in the German Federal State of Hesse with the following lead project partners: the HfG Offenbach University of Art and Design (design; consortium lead), the Frankfurt University of Applied Sciences (transportation planning), Goethe University Frankfurt (mobility research), and the Technical University of Darmstadt (media and communication technology/architecture): www.project-mo.de.

02 The metropolitan areas referred to here are the sixteen largest German cities with a combined population of about 14.5 million; see Regional Statistical Area Type: https://www.bmvi.de/SharedDocs/DE/Artikel/G/regionalstatistische-raumtypologie.html.

individual motorized traffic, the dominant form of transport, must therefore be reduced—without restricting personal mobility. This will not be possible through technological innovations alone; it will require changes in behavior. In the future, we will get around differently and in a more environmentally friendly way. Accordingly, the future tasks of mobility design include the development of innovative methods, as well as of specific tools and strategies, that will positively promote socially and ecologically sustainable projects in the mobility sector. Furthermore, these must be made more efficient and more visible to increase their acceptance among the population.

Toward a New Networked and Environmentally Friendly Mobility

The way in which individual mobility needs can be met is essentially determined by the available transportation system with its modes of transport, supporting infrastructure, and associated control and supply systems. To facilitate use of a transportation system, access to it must also be both physically and cognitively barrier-free as well as economically feasible. In Germany, enabling mobility is largely the responsibility of the state. Local authorities, the states, and the federal government are legally responsible for providing transportation as part of the general provision of public services. Individual mobility should be possible for all, even for those who do not have a car (Schwedes 2011). To guarantee the minimum level of mobility, public transportation policy has been given the responsibility of providing collective transportation by bus and train.

The focus of transportation policy was, and still is, on expanding the roadway system to provide a »free ride« for the privately financed automobile, the engine of the mass motorization of the postwar period. The aim is for traffic to flow as smoothly as possible so individuals can cover geographical distances, and thus change their locations, without any difficulty. It seems that individual, autonomous mobility can only be conceived in terms of the automobile. Having your own car guarantees a constantly available means of transport, with the implicit assumption that all of the necessary infrastructure is available, while ignoring the fact that even today the acquisition of a car is a major challenge for low-income households (as indicated by the low level of car ownership among the lower social strata—Nobis and Kuhnimhof 2018). However, owning a car also fulfills the need for privacy, autonomy, status, and enjoyment (Hunecke 2006), with an enduring effect on the experience of mobility. It literally embodies personal freedom and stands for being unconstrained in a self-propelled vehicle. It is flexible and comfortable to use. Not only that: the car as a product is a highly emotionally charged object that people identify with. It is a status symbol, part of memories, part of the family (Geuenich 2020). How one moves and with what is not a trivial question, for the automobile not only makes individual mobility possible but also helps people seek self-affirmation and personal experience (Vöckler and Eckart 2022).

The crucial question is therefore whether autonomous, individual mobility is only guaranteed by the car as a product or whether the transportation system, which is oriented toward individual automobility, can be transformed in such a way that the feeling of personal freedom can be transferred from the car as an object to the act of moving itself (as the experience of self-mobility—Rammler 2003; Eckart and Vöckler 2018). After all, from an overall societal perspective, against the backdrop of the societal transformation toward sustainability, the question arises as to how the transportation system can contribute to the »good life.« That is, not as the fulfillment of promises of individual happiness, but rather as participation in a transportation system that is economically feasible for all, as well as ecologically and socially viable. This requires an understanding of mobility that goes beyond the dichotomy of private (auto-) mobility versus public transportation and instead sees mobility as an overarching public task encompassing all forms and modes of mobility (Schwedes 2021)—a transportation policy challenge that still needs to be addressed.

The feasibility of intermodal and environmentally friendly mobility that links public transport services with sharing services, and includes walking and cycling, is due to a revolution in transport technology based on the two principles of networking and sharing. With the availability of mobile internet via smartphones and tablets (and other digitally based information and communication devices in the future), new, intelligent forms of mobility are possible. We are no longer dependent on our own vehicle and in the future will easily be able to use a variety of different modes of transportation (including shared automobiles) on one route (intermodal mobility). Digitally supported mediation platforms make environmentally compatible and intelligent mobility technically possible: shared modes of transportation are more efficiently utilized. In this way, the focus is shifting away from the product toward usage, which is now no longer tied to a specific mode of transport. With innovations in usage linked to digitalization, product innovations focused on vehicle technology (such as electric power transmission technology) appear to be just one building block within a broader systemic transformation that begins with a new way of using transportation systems (Rammler and Sauter-Servaes 2013).

However, this brings into closer focus the mobility experience, which occurs on an individual basis in interaction with the transportation system. Mobility—understood as the individual's ability to move physically in space, whether on foot or by transport modes such as the bicycle, train, bus, or automobile—is a basic need and part of everyday life. Mobility stands for self-mobility, in contrast to the concept of transportation, which refers to the movement of people and goods (as an actual change of location). Mobility refers to the individual experience of interacting with other mobile people, as well as objects, information, spaces, and the infrastructure and technical systems that support them. This means that the existing transportation system with its mobility services is subjectively perceived, experienced, and evaluated, and thus cannot be understood in isolation from lifestyles, consumer desires, and behaviors (Götz et al. 2016). Mobility systems therefore not only consist of material infrastructures and modes of transport (the transportation system), but also of cultural concepts and symbolic languages that operate within them; they are based on social practices and associated forms of subjectification (Urry 2004; Vöckler and Eckart 2022). Therefore, the concept of the mobility system is understood here as a dynamic structure embedded in everyday culture, which only emerges when used by moving individuals (Eckart and Vöckler 2022b).

Consequently, the mobility system is to be understood in terms of use and from the individual's point of view. What are the practical benefits of my chosen mode of travel, and how can I use it without hindrance (instrumental utility)? What kind of experience will I have while using it, and how will my sense of well-being be enhanced (hedonistic utility)? What significance does this form of mobility have for me, and can I identify with it (cognitive utility) (Kelly and Sharot 2021)? To enable this new freedom of mobility, it is therefore necessary to have a seamless interaction between modes of transport (which is primarily a question of organization and planning). It also requires the comprehensive design of an environmentally friendly mobility system (including its digital expansion). And in doing so, people's needs must be taken into account, and these are not merely instrumental (Haustein in this volume). This is the key challenge for mobility design, which mediates between users and the mobility system (»Offenbach Model,« Vöckler and Eckart in this volume). How is access to the mobility system improved, how are experiences positively shaped, and how is identification facilitated?

Mobility Design

Mobility design follows the guiding principle of user-oriented and environmentally friendly transmodality.[03] It views mobility as an entirety, which manifests itself as the need and ability to move in space. Both the individual basis for action and the spatial and structural context determine mobility capacity and behavior. As a significant aspect of

03 The following definition is based on a working paper written jointly by the research partners already mentioned in the introduction to the previous volume (Mobility Design, Vol. 1, Practice) (Vöckler and Eckart 2022: 16–17). Concordances are not explicitly indicated here.

social participation, the ability to move must be granted to as many population groups as possible. Mobility design contributes to this significantly as an interface between people and spatial structure.

The prerequisites for designing environmentally friendly mobility are the availability of environmentally friendly mobility services, sufficient infrastructural provision, and the smooth organization of functional processes within the mobility system. The design of mobility systems, of movement processes in complex mobility spaces, opens up a new dimension of the sustainable design of social transformation processes. In this context, the concept of design is understood in transdisciplinary terms as mobility design (Blitz et al. in this volume). Traditional scientific fields of investigation such as transportation planning, urban development, information and communication technology, and the social sciences are linked to design research on mobility. However, mobility design always includes the subject-specific design of user interaction with the mobility system. The design of new sustainable and networked mobility is thus divided into two different, but interrelated fields of action:

- in a transdisciplinary, comprehensive design of the mobility system that considers its organizational and institutional logic, as well as the political parameters including ecological, economic, and social factors;
- in a design-specific configuration of user interaction with the mobility system. Here, the focus is on intermodality, that is, how different forms of mobility can be linked with each other in a frictionless manner according to user needs.

Mobility systems encompass the mobility needs of users, the existing transport infrastructure, and all available means of transport. Mobility design determines the interaction of users with the mobility system, which consists of time- and movement-based usage processes, the physical form and organization of products and spaces, the digital interface, the logic of information dissemination, and the underlying technical systems. This requires mobility design to be systemically oriented: this approach necessitates the pooling of diverse mobility-related expertise. Mobility design should therefore be seen as an interdisciplinary task. Design is the integrating element since it mediates between people and mobility systems through design decisions and shapes user experiences (Vöckler and Eckart in this volume).

The design-specific configuration of mobility is based on the mobility needs of the individual user. It

- affects attitudes, values, and perceptions, and thus behavior and perception, through design decisions;
- focuses on the influence of semantic design aspects on the perception and use of mobility systems beyond the functional aspects;
- enables access, facilitates orientation, communicates meaning, builds familiarity through recognizability, and generates acceptance through quality (comfort and value).

Individual appropriation and evaluation are decisive factors for acceptance. Therefore, when the existing transport system is transformed into a multimodal mobility system, this must be understood as a function. And acceptance is only achieved if concrete use leads to a positive mobility experience.

Chapters and Themes in this Publication

The contributions in the first section address the tasks and challenges of mobility design as a field of research. By way of introduction, Ole B. Jensen (Aalborg University) summarizes the beginnings of the »mobility turn« in sociology and human geography, as well as the shift toward »mobility design« in architecture and design. Beginning with the physical interaction of a subject with the mobility system and the accompanying multisensory and affective experience, this chapter outlines how this interaction is characterized by the design of affordances and atmospheres. Following this, the model of human-centered mobility design developed at HfG Offenbach University of Art and Design is presented. Thus, for the first time, a systematic and conceptual modeling of the requirements for the design of intermodal, environmentally friendly mobility systems will be available for discussion (Vöckler and Eckart). The transdisciplinary perspective on mobility design is illustrated in the next contribution through interdisciplinary collaboration between mobility research, urban and transportation planning, and design in the implementation of bicycle lanes. By bringing together different disciplinary approaches, theoretical assumptions, and methods, it is possible to achieve an overall increase in knowledge for mobility design (Blitz, Lanzendorf, and Müggenburg). Finally, the concept and development of the digitally supported, interactive »Mobility Design Guide« is introduced. This guide prepares the relevant contents for a future mobility design for the target group of planners and designers as well as decision makers from politics and business; it also documents the results of the interdisciplinary research project (Krajewski, Reitmaier, Vöckler, and Eckart).

The second section focuses on »Connective Mobility.« The contributions assembled here address central aspects of the design of new mobility structures. To introduce the section, Sonja Haustein (Technical University of Denmark) provides an overview of the most important psychological theories of behavioral changes toward transportation, and how these mechanisms of change are linked to the sociocultural and physical environment. This contribution is followed by a presentation of the long-term focus group method; this research project was supported by focus groups across a four-year period. Participant feedback (as knowledge transfer from laypersons) was incorporated into further work (Schäfer, Stolte, and Reinfeld). In the next chapter, from the perspective of urban design and planning, the question is explored as to which methods and processes need to be established in order to transform the car-oriented city into the livable city. Using Copenhagen as an example, this study demonstrates that integrated holistic concepts are needed to establish quality agreements for the city as a whole, and to develop solutions tailored to the place and the users. It is therefore less of a spectacular single solution and more a holistically oriented planning culture that enables successful transformation (Rudolph-Cleff and Hekmati). Focusing on practice-led design research, the following chapters present the specificity of the design methodology within its situational, systemic, and contextual orientation. Using examples of the design of transit situations in public transport, it is shown how innovations become possible via a systemic and user-oriented design approach (Moeckl, Schwarze, Eckart, and Vöckler). The final chapter here shows how design research can anticipate and experimentally develop new, intelligent intermodal mobility services (on the basis of current technological developments)—in order to foster discussions on the development of future mobility (Moeckl, Schwarze, and Eckart).

In the third section, »Active Mobility,« the contributions discuss urban planning principles, strategies, and devices that promote physically active mobility (walking, cycling). These authors thus broaden the view of mobility design as an important factor in strengthening health and quality of life in growing urban regions. Ralph Buehler, Denis Teoman, and Brian Shelton (Virginia Tech) begin with a comparative study of the urban, political, and organizational structures and initiatives that have positively influenced cycling in the cities of Washington, DC, and Frankfurt am Main over the past twenty years. In their conclusion, the authors illustrate how both of these auto-oriented cities (without long cycling traditions) succeeded in moving toward integrated planning in small increments, where the adaptation of infrastructure was combined with other support measures (including speed limits for motorized traffic). Martin Knöll's essay picks up from here at the level of urban design. He examines the question of which new instruments are necessary and beneficial to the optimization of temporary traffic experiments in keeping with the sustainable, healthy development of the urban core. Focused on the year-long closure of Frankfurt's Mainkai, this essay recognizes that the promotion of health and physical activity is generally well-anchored in the city's long-term urban concept and master plan. However, there is a considerable deficit in terms of strategic planning, communication, scientific evaluation, and sufficient participation of temporary experiments, which has so far impeded a more far-reaching realization of urban transformation processes. The contribution by Jenny Roe and Andrew Mondschein (both University of Virginia) continues the thread by calling for much greater consideration of people's mental health and cognitive capabilities when designing future streetscapes. They present a new model that adds qualitative aspects such as well-being, experience, perception, and social interaction to the traditional quantitative factors of »active travel« (focused on length and frequency of distance traveled), while integrating these with assessment methods such as EEG testing, as well as pulse and perspiration measurement. Even though studies that address design interventions in urban spaces and scientific evaluation using mobile sensor technology are still rare, the authors present a convincing way of making investments tangible through measurable effects on the quality of mobility and mental health.

This section concludes with three chapters examining practice-led research and design projects. The example of cycle street configuration demonstrates the need for designs based on user perspectives. In collaboration with social science mobility researchers, design decisions are evaluated using surveys, and the results incorporated in further developments, thus providing a model approach (Albrecht and Blitz). Based on the example of the bicycle, the next chapter illustrates how bicycles can be approached in a systematic way, not only as a commodity and a mode of transport that is a product of design, but also as a component within an environmentally friendly mobility system seen from the user perspective—which in turn leads to innovative redesign. This approach can also be applied to transport infrastructure such as bicycle bridges (Moeckl, Schwarze, and Eckart). Finally, Lakshya Pandit presents the results of a study on the Mainkai in Frankfurt, where 30% more cyclists and 1150% (!) more children were counted on bicycles while it was closed to motorized traffic in 2020 (Pandit et al. 2020). After it was reopened to motorized traffic in 2021, the number of bicyclists dropped to an even lower number than what had been recorded before the experiment, back in 2019.

The contributions to the section »Augmented Mobility« focus on the transformation of existing transportation systems through the possibilities afforded by digital information exchange, as well as through the application of digitally supported investigation tools. Weert Canzler and Andreas Knie (Wissenschaftszentrum Berlin) explain how public transport can be reorganized through digitalization in concert with the integration of (partially) autonomous on-demand shuttles, thus making the system considerably more efficient and user-friendly—provided that appropriate policy regulations are implemented. The next chapter describes how »serious games« and »gamification« can be deployed to promote environmentally friendly mobility behavior. In this way, users can be motivated to change their mobility behavior (Göbel, Tregel, Müller, and Steinmetz). In the contributions that follows, interdisciplinary collaboration between cognitive psychology and design suggests that virtual reality simulations can provide an empirically valid means of assessing the impact of designs and plans, even before they are implemented (Schwarze, Vöckler, Hinde, David, Le-Hoa Võ, and Eckart). Finally, an essay on the development of a game app, a collaborative effort between media and communication technology, design, and transportation planning, illustrates how a mobile, context-sensitive game can promote climate-friendly behavior (Reitmaier, Müller, Reinfeld, Tregel, Krajewski, Schäfer, and Göbel).

In the last section, »Visionary Mobility,« the future prospects of new mobility are addressed. At the beginning of this section, Claire Gorman, Fábio Duarte, Paolo Santi, and Carlo Ratti (MIT Senseable City Lab) present research projects that demonstrate novel possibilities for traffic optimization based on data linkage and analysis. The starting point here is no longer the physical product but the digital network, which enables a new, more flexible adaptation of traffic to usage. The following chapter explores how the impact of changes in user expectations resulting from digitalization may influence the possible design of mobility systems. It then discusses the contribution that future mobility design could make to societal transformation processes (Krajewski and Reitmaier). Finally, in his essay Stephan Rammler (IZT—Institute for Futures Studies and Technology Assessment) explores the challenges that can be expected in the configuration of socioecological mobility transformations through design. He sees mobility design as an intermediary discipline at the interface between a wide range of urban, spatial, and transportation-related sciences on the one hand, and design and planning practices together with the user experience on the other.

Outlook

This publication outlines a new perspective on the transformation of existing transportation systems into networked and environmentally friendly mobility systems, which are consistently developed from the user perspective: that is, Mobility Design. Based on user needs, the conclusions that are drawn with respect to planning, design, and scientific evaluation are presented for discussion. The interdisciplinary orientation of most of the chapters gathered here shows how knowledge can be produced that transcends disciplinary boundaries in the context of problem-oriented applied research—here, on climate change and the resulting essential ecological transformation of transportation systems. Interdisciplinary collaborations resulted in mutually interacting cognitive methods that, in our view, provide the basis for a yet-to-be-developed transdisciplinary mobility design. The essays presented here in the context of research collaborations among the authors go beyond fundamental scientific research and are aimed at supporting societal transformation toward sustainability.

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Designing and Researching Intermodal Mobility

Peter Eckart and Kai Vöckler

The implementation of intermodal mobility—the interlinking of diverse forms of mobility along a single route—initiates a revolution in mobility technology that is based on the principles of networking and sharing. Environmentally sustainable and intelligent mobility is becoming technically more feasible as users are able to access the internet en route, linking digitally supported intermediary platforms; transport resources that are shared collectively are simply more efficient. From a user perspective, all these mobility options—walking and cycling, bus or rail, shared automobiles—should be conceived as an interconnected, intermodal mobility system that needs to be flexibly adaptable to individual mobility decisions. Only design can convey the significance and value of these new, progressive modes of mobility to users with immediacy and while they are moving. What is necessary, therefore, for purposes of design work is a systemic perspective that bears in mind all components of the mobility system: from bicycle racks to transport vehicles, and all the way to station concourses. Each of these individual elements communicates to users forms of access to the mobility system as a whole, including its linkage with digital information and communication. The task of design is to mediate between the human individual and the mobility system to have a positive impact on user experience. Design optimizes access while enabling identification (the »Offenbach model«).

Accordingly, the focus of design research is on the quality of the mobility experience of users during their interaction with the intermodal mobility system. In order to arrive at well-founded assessments of the impact of design decisions, dynamic two-dimensional visualizations are utilized on the basis of transport system data to develop mobility scenarios, which are in turn tested and evaluated in virtual-reality test situations. With the integration of various user groups (participatory design), this research approach allows us to conceptualize fundamental and empirically grounded design approaches. The results can then flow into the development of design guidelines and concepts. A further resource for design research is the development of concepts in relation to concrete problematics that anticipate desirable developments, which then become possible through the design artifact. Fundamental, always, is a systematic approach that consistently conceptualizes the intermodal mobility system as a dynamic system that is configured through active use by mobile individuals (connective mobility). The design artifact, then, is to be understood as a mediating element within the larger mobility system. A particular challenge for designers of intermodal mobility systems is the configuration of mobility hubs. For environmentally friendly mobility, particular attention must be devoted as well to the considerable importance of nonmotorized mobility (active mobility). And emerging together with the formation of a digitally supported information and communication space, not least of all, is an extension of the mobility system (augmented mobility), one that opens new perspectives for designing modes of interaction between the human individual and the mobility system, which in turn require further investigation.


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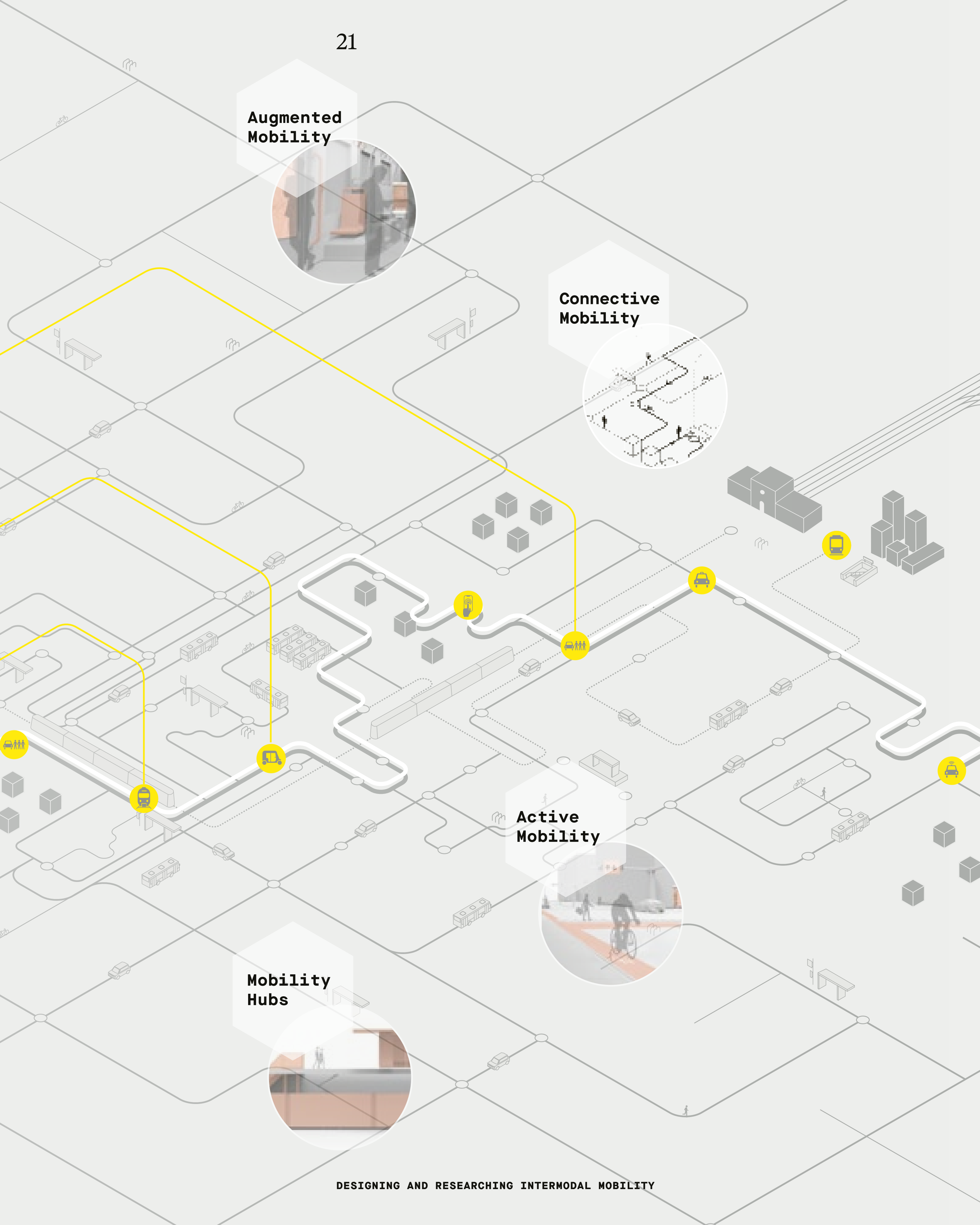
Augmented
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Hubs

Mobility Design

Mobilities Design

Affordances, Atmospheres, Embodiments

Ole B. Jensen

This chapter introduces the new research area of mobilities design. It situates the development of mobilities design in relation to transportation and urban planning, urban design, and architecture while also connecting it to the humanistic and social sciences that it embraces. Some of the pivotal concepts within the mobilities design research field are affordance, atmosphere, and embodiment. The chapter will explore the relationship between these key concepts, specifically, and discuss how they form an important foundation to the mobilities design field. The chapter ends with some key pointers for future research within this emerging and growing field.

Introduction

Humans are mobile animals. We walk and run by our own bodily force, and our mobility technologies have shaped the way we live in ways not to be underestimated. Sailing, flying, driving across space and time at scales from neighborhoods to the globe (and these days even beyond with the »billionaires' race to space«), we are indeed »homo movens« (Vannini 2010). Our cities have over the last century taken shape after the most influential of all mobilities modes: the car. The ways in which flying has contributed to cultural exchange and globalization (and carbon dioxide emissions) is also hard to underestimate. We are mobile as a species in our »naked capacities« (Ihde 1990). However, the artificial landscapes of urban infrastructures that now has become »second nature« are also only inhabitable via mobility.

In the early days of the »mobilities turn« most disciplinary resonance was found in sociology and human geography. However, for more than a decade a turn to architecture and urban design has enabled the establishment of the research area of »mobilities design« (Jensen 2013, 2014; Jensen and Lanng 2017). Paying attention to the role of design in the making of the infrastructural landscapes of contemporary mobilities was only one dimension hereof. Another was a turn to the concepts and vocabularies within architecture and design enabling researchers to develop a sense of materials, spaces, volumes, voids, shapes, forms, and so forth. Learning from the design fields has also meant being inspired by the critical and creative approaches to shaping and making cities. To broadly simplify the matter, the social sciences developed a fine-tuned sense of problems, but it takes the architecture and design fields to enhance a sense of potentials. Mobilities design merges the critical sense of problems with the creative understanding of potentials in a research strategy that is much better equipped to understand the mobile life conditions of contemporary urbanites.

This chapter is structured in the following manner. After the introduction, a section follows explaining the shift from transport to mobilities and then further on to mobilities design. To explain in more detail the capacities of mobilities design research, three key terms are then related in the framing section. The notion of affordances, atmospheres, and embodiments constitutes the rough contours of a theoretical framework for understanding mobilities design. The chapter ends with some concluding reflections and thoughts about future research.

From Transport to Mobilities (Turn 1) to Mobilities Design (Turn 2)

The multiple movements across and between cities have deep repercussions for who we are and what relationships we can engage in. This discussion is already well known under the rubric of transport (Shaw and Hesse 2010). Movement from point A to point B has shaped the form of cities and nation-states and has become a huge and globe-spanning logistics operation. Getting people, goods, and information from A to B in the shortest possible span of time, via the quickest routes, or most cost-efficiently has become the territory of transportation engineering and planning. However, there is more to mobilities than movements between A and B! The ways in which mobilities shape identities and societies has been the key interest of the »mobilities turn,« which emerged within social science around the millennium (Jensen 2015; Sheller 2021). Moving »beyond societies,« as Urry (2000) titled his agenda-setting book *Sociology Beyond Societies*, meant focusing on mobility and immobility in networks rather than on static structures. The turn to mobilities has roots back in the early social sciences (Jensen 2015; Simmel 1994), but with the emergence of a new interdisciplinary way of thinking about cities and societies in the light of mobilities across sociology, geography, planning, and anthropology a new agenda was shaped. Mobilities research is thus an important rethinking of the role that movement and transportation have in making societies. It moves beyond the instrumental and into the more complex questions of identity, belonging, and situatedness of human practice.

We might say that transport has been about instrumental movement from A to B in efficient and safe ways. Opening up to mobilities does not remove those concerns, but rather adds two vital dimensions: experiences and aesthetics; and power and sociality. If we think of these four dimensions—instrumentality, safety, experience, and sociality—then the turn from transport to mobilities can be said to add the latter two to the first two. In the last ten to fifteen years, mobilities design has made a second turn, exploring the meticulously detailed relationships between the »made« (or designed) spaces, infrastructures, and technologies, and moving human bodies. The lesson learned from engaging with design »sensitizes us to the detailed entanglements with matter, surfaces, volumes, physicality, etc. that we know are important for the sensorial experiences of mobile subjects enrolled into various Mobilities systems and infrastructures« (Jensen 2016, 594).

The habitats of contemporary urbanites are huge artifacts. Urban networks and infrastructural landscapes are »made«; hence, the focus on design as something that explores »making« (Gänshirt 2021). As mentioned, there are two dimensions to mobilities design research. One is the enhanced understanding of the role of materials, spaces, and artifacts. The other is concerning the processes within design. It is what some research environments have come to see as critical and creative approaches to look for potentials as well as problems (Jensen and Lanng 2017). The argument for mobilities rather than transport is thus well explained. However, why term it mobilities design and not, for example, »traffic architecture« (as proposed by Buchannan 1964). The argument here reaches back to the situated and pragmatic focus on the mobile situation (Jensen 2013). What is of interest is that which affords a specific mobile situation. Honing in on architecture is simply not precise enough. We might face cases where the mobile situation is shaped by algorithms of traffic-light coding or the service design of ticket systems. These dimensions are hardly architecture, so the pragmatic research interest is much better taken care of if we use the broader notion of design. To put in one line: we are exploring mobilities, not transport; design, not architectures:

Affordances, Atmospheres, Embodiments: Framing Mobilities Design Research

The key question to mobilities design research is: »what design decisions and interventions afford, enable, or prevent concrete mobile situations?« (Jensen 2016, 590). To explore this, a number of relevant and interesting theories and disciplines might be mobilized. This chapter focuses on three key concepts that will enable us to get closer to understanding the actual, situated, and practical dimension of mobilities. In short, we need concepts for a vocabulary that enhances our understanding of what enables the mobile practices by humans (see Jensen and Lanng 2017 for a more elaborate argument).

Affordances The concept of *affordance* was coined by environmental psychologist James J. Gibson (1986). The affordances of an environment are what it »offers« the animal, what it »provides« or »furnishes« (Gibson 1986, 127). Gibson argued that:

> Air affords breathing, more exactly, respiration. It also affords unimpeded locomotion relative to the ground, which affords support … water is more substantial than air and always has a surface with air. It does not afford respiration for us. It affords drinking. Being fluid, it affords pouring from a container … a horizontal, flat, extended, rigid surface affords support (Gibson 1986, 129–35).

Affordance is a relational term. This means that we are looking at what a ramp or a bench may do or enable in relation to a human body. This is precisely why the situational mobilities research has found value in the notion of affordance (Jensen 2013). With its focus on the staging of mobile situations, the notion of *mobility affordances* was articulated to capture »how the specific relation between the moving body and its material environment opens up (or narrows down) to particular modes of mobilities, different speeds, trajectories etc.« (Jensen 2013: 120). Mobilities design research explores mundane mobilities practices that could be:

> a fine-grained asphalt floor of a road (one of the most ubiquitous types of pavement in spaces of mobilities), which affords frictionless and smooth car rides; or a traffic signal, which affords the ruled organization of intersecting mobilities and sets the scene for embodied and interactional mobile situations, such as waiting in a crowd with other pedestrians. Affordance is thus a concept that enables us to target the performative effects of mobile situations through the relational mobile subject—body—materiality couplings (Jensen et al. 2016, 30).

Much more could be said about affordances, but hopefully its relevance to mobilities design research is clear.

Atmospheres The second concept that we will introduce as a cornerstone of mobilities design is the notion of *atmosphere* (or ambience). This is a vital concept to engage with the added dimensions we saw with the first turn from transport to mobilities. If we are to understand how mobilities relate to experiences, aesthetics, power, and sociality we need concepts like atmosphere. Bissell argues that »affective atmospheres are central to everyday conduct whilst on the move since different atmospheres facilitate and restrict particular practices« (Bissell 2010, 272). And Borch points to the fact that atmospheres exercise a »subtle form of power« where people's behaviors, desires, and experiences are managed and controlled without their awareness (Borch 2014, 15). Atmospheres shape a »manifestation of the co-presence of subject and object,« and are characterized as the »prototypical ›between‹ phenomenon« (Böhme 1998, 114). And a final quote to include from one of the founding figures of the mobilities turn, John Urry: »Atmosphere is in the relationship of peoples and objects. It is something sensed often through movement and experienced in a tactile kind of way, what Thrift terms ›nonrepresentational‹ practices (1996)« (Urry 2007, 73).

We register atmospheres in airports, on streets, on the freeway, and all other places where we are on the move. From research into how hostile architecture or »dark design« is excluding homeless people in cities via spikes in the ground under bridges or leaning benches affording lying bodies to fall to the ground, we see a connection between mobilities and atmospheres (Jensen 2019). When homeless people move through the city in search of night shelter, the increasing number of dark design interventions orchestrates what has been termed an »atmosphere of rejection« (Jensen 2020). What this means for mobilities is that the city's rejecting response to the homeless creates »go and no-go areas« in the city and over time contributes not only to a specific atmosphere for the shelter-seeking, but also to a »jigsaw puzzle« of spaces to avoid and spaces that are attractive due to their affordances (Jensen 2019).

Embodiments The bridge from affordance and atmosphere to embodiment is not hard to see. Anderson argues that atmospheres emerge in the relational »assembling of the human bodies, discursive bodies, non-human bodies, and all other bodies that make up everyday situations« (Anderson 2009, 80). *Embodiment* means including the multisensorial and affectual experiences of the moving subject. Too little attention is given to the crucial question, »How does it feel?« within the transportation. However, we all recognize that the air quality, the temperature, and the kinesthetic and haptic experiences that shape our mobilities experiences are more than simply objective dimensions. We realize this whether we are flying in different sort of aircrafts (Jensen and Vannini

2016) or if we are taking an air-conditioned sky train instead of an overcrowded, non-air-conditioned bus (Jensen 2007). We may put this in very simple terms: we are doing mobilities (Jensen 2013). Hence, the role of embodiment becomes vital to our analysis and understanding (Jensen 2016, 593).

The relationship between bodies, spaces, and vehicles is complex. Multiple senses and affect enter the equation, as does the fact that our bodily boundaries might have to be rethought. Gerontology put focus on what is termed the *extended body* as an illustration of this phenomenon (Reynolds 2018). According to this line of thinking the body is only one component of a full mobile situation. Furthermore, we may start reflecting that we are »touching the world« in many more different and important »critical points of contact« (Jensen and Morelli 2011) than we normally think of. The body has an »osmotic« or open relation to the world as it »extends« into relations with artifacts and spaces (Jensen 2016; 2021). The American philosopher Richard Schusterman articulates it very directly when he states that:

> To focus on feeling one's body is to foreground it against its environmental background, which must be somehow felt in order to constitute that experienced background. One cannot feel oneself sitting or standing without feeling that part of the environment upon which one sits or stands. Nor can one feel oneself breathing without feeling the surrounding air we inhale. Such lessons of somatic self-consciousness eventually point toward the vision of an essentially situated, relational, and symbolic self rather than the traditional concept of an autonomous self-grounded in an individual, monadic, indestructible and unchanging soul (Schusterman 2008, 8).

In other words, when we are in a car, on the bus, in the bike saddle, or simply walking down the street, we are sensing a considerable number of things. In terms of consciousness, we might foreground and background certain things like paying attention to the red and green light at street crossings, other vehicles and bodies in the environment, or signage, and so forth. It is precisely this holistic and situational complexity we need to understand (Jensen 2013).

The interlinking of affordance, atmosphere, and embodiment is not the full story about the theories underpinning mobilities design research, but these are key terms and, in particular, their interrelationship is vital for showing the move from transport over mobilities to mobilities design.

Concluding Reflections

Mobilities design research may be situated and articulated in various ways, but one school of thought that has emerged is material pragmatism (Jensen 2017; Jensen and Lanng 2017). It is too much to engage in a deeper exploration of the ontological and epistemological assumptions and underpinnings of material pragmatism here, but a few indications can be made:

The analytical position of material pragmatism points to the actual effects and situations and not some abstract and generalized perspective. Material pragmatism asks »what enables this particular mobile situation?« and in answering it seeks to move beyond subjects standing before objects, humans before spaces, people before infrastructures. Rather, material pragmatism argues for a situated, holistic, materially sensitive understanding of mobilities (Jensen 2017, 10).

The research agenda of material pragmatism is thus one that invites further explorations of mobilities design. Surely more conceptual and theoretical work is needed. Moreover, there is a need to explore more methods reaching across the qualitative and quantitative data trench as one thing, but also to include more technologically innovative approaches (sensor technology, cameras, geo-sensitive approaches, eye-trackers, etc.) to »orchestrate« mobilities design research methods (Jensen et al. 2020). Following these aspirations, a future material pragmatist research agenda for mobilities design should explore the creative potentials of design thinking and practice in relation to building things, intervening, and mocking up experiments in urban spaces in a 1:1 scale as well as exploring the potential of a critical and creative mindset, and creative processes of »what if?« design scenarios.

The latter is where the potential for public involvement and critical cocreation is located. Hence, there is plenty of work to do for fulfilling a future material pragmatic mobilities design research agenda.

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The Offenbach Model

Human-Centered Mobility Design

Kai Vöckler and
Peter Eckart

The Offenbach model, developed as part of a design research project aimed at promoting environmentally friendly mobility at HfG Offenbach, places people and their needs at the center of a transportation system that brings together climate-friendly mobility options.[01] This design research is not focused on the organization and planning of traffic flows and systems, but rather on the configuration of an intermodal, environmentally friendly transportation system with its data and physical environment. It also considers shared transport modes and spaces while in use, as well as the mobility experience. Since the actual space in which users move is already digitally supported to a great extent and thus increasingly overlaid with online information, this mobility experience is being expanded to include the virtual dimension, and the digital expansion of mobility space has been incorporated accordingly in the Offenbach model.

As a means of introduction, the concept of human-centered design will be explained below. Next, this essay will focus on the Offenbach Model developed from this concept. This model aims to capture and define terms that guide the design of intermodal mobility systems. In the section following, the development of terminology is presented in reference to findings from design studies, social science mobility research, and urban and traffic planning. This essay concludes with an overview of the future challenges of design that considers the way information increasingly pervades physical space and how this affects mobility design.

Human-Centered Design

Design mediates between users and their environment (products, systems, technologies, services) and anticipates new forms of use, for which it shapes their aesthetic impact and articulates their symbolic meanings as relevant offers. Design enables interaction and influences the behavior of users through form-making decisions. Accordingly, design shapes the user experience (Vöckler and Eckart 2020). Design refers to the affective impact (the aesthetic dimension), usability (the practical dimension), and meaning (the symbolic dimension) of artifacts as they are developed and formed through design (Vöckler 2021). This corresponds to the analysis of the design task in the creation of artifacts developed at HfG Offenbach in the 1970s as the theory of product language (»The Offenbach Approach«) (Gros 1983; Fischer and Mikosch 1984; Gros 1987). In this approach, the human-object relationship is defined in design theory as the actual design task; it is only through the interaction of human and object that meaning emerges (Gros 1976). Meaning—and thus the understanding of designed objects—encompasses the aesthetic impact of the formal structuring that unfolds through perception, with its accompanying affects. These play an essential role in determining to what extent the interaction is already evaluated positively or negatively on the perceptual level: feelings of pleasure or displeasure, as they are modulated, for example, through a clear or even confusing structure (formal-aesthetic functions). In addition, there is also the understanding of how objects can be used and what they offer (indicating functions, i.e. of possible uses; this corresponds largely to the affordances introduced into design theory by the cognitive scientist Donald Norman. See Norman 1988; Jensen in this volume). Furthermore, artifacts have social and cultural references; they generate opportunities for identification, which in their symbolic meaning fosters self-assurance (symbolic functions; see Vöckler 2021). They are a means of social distinction (status), but also facilitate identification in or with a culture (here: mobility culture; see Götz et al. 2016). Accordingly, artifacts create meanings that go far beyond their practical functions (Krippendorff and Butter 1984; Steffen 2000). Beyond their formal structure, the effect of designed objects and spaces also reveals symbolic meanings that relate to their sociocultural context. They can bring about new and fascinating ways of seeing, and thus of valuing, the (designed) environment. At the same time, design can express respect for its users through the symbolic meanings of the materials used as well as through the language of form.

The interaction of humans with objects (human-object relationship) was further developed in design theory in the concept of the interface. Today, an interface is usually only understood as an interface between a human being and a technical device (as well as between technical devices). In principle, however, the term *interface* refers to the interaction of users with a product in a course of action (Bonsiepe 1996). Accordingly, the space of interaction is understood as the interface. If the focus of design is on the interaction itself, then it becomes clear that the understanding of designed objects is never completely predetermined or preformed, neither in the subject nor in the object (Krippendorff 2006).[02] Moreover, with the focus on interaction, the scope of designing products has expanded to include processes, situations, and (technical) systems. Human-centered design therefore generates a fundamental understanding of the interplay between perceptions, actions, and the emergence of meaning in the interaction between humans and their (designed) environment (Krippendorff 2006). Meaning emerges through application, in use, and in the interplay of perceptions and actions. For this reason, designers must be able to grasp how users understand products and how design decisions can have a positive impact on this understanding.

The focus of the Offenbach model of human-centered mobility design is on interaction with the concrete physical space in which users physically move. However, with the utilization of a technical medium that is mobile and connected to the body, such as the smartphone in common use today, the perception of the environment has changed, especially to the extent that it stages new environments (in particular as an enveloping private sphere). This affects self-positioning: both functionally in orientation (navigation), but also symbolically and emotionally in the form of self-representation in informational space, which at the same time has a reciprocal effect on self-positioning in real space—validating me as an individual in interaction with the digitally augmented concrete environment. Even if the smartphone being carried is not used or is only used temporarily, this has an impact on the subjective sense of security in real space and increases the sense of one's own self-efficacy (autonomy) (Colomina and Wigley 2019). Personalized access to the mobile internet offers great opportunities for positively influencing mobility behavior through motivational feedback strategies or even gamification approaches (see Göbel et al. in this volume). Accordingly, the specific effects of digitally supported extensions of the interaction space have been taken into account in the development of the model and its guiding concepts. Major changes can be expected in this area in the future (see the outlook section at the end of this essay).[03]

Modeling and Definition of the Interaction Areas

Models serve as bridges between theories and real-world applications. Crucial for the development of any model is how the phenomenon to be modeled is abstracted. This abstraction process is accompanied by a corresponding concept formation. Concepts are understood here as tools with which we describe (and order) phenomena, and which make those phenomena accessible to us by opening up new perspectives, thereby structuring the design exercise (Eckart 2021). The model presented here follows a pragmatic approach that focuses on the interaction between users and the mobility system, that is, on subjective actions: human-centered mobility design. At the same time, this approach allows the mobility system to be designed to ensure successful interaction. However, this also requires a more precise definition of the different types of interactions.

In two specialist workshops, key concepts were identified that are essential for determining design parameters (↳Fig. 1).[04] These were assigned to three interrelated interaction areas that capture different qualities of interaction with the mobility system. These are

- the *access*, which encompasses all the factors that make successful and barrier-free use possible in the first place, essentially relating to the functional side (the practical dimension);
- the *experience* had with and during use, with the social-emotional influencing factors of its affective impact (the aesthetic dimension);
- the *identity*, which enables identification with the mobility system and conveys its meaning, thus promoting an emotional bond (the symbolic dimension).

Guiding principles were developed for a mobility-space design oriented toward user needs, by incorporating cognitive and design science findings regarding interactions during usage acts, which emphasize the importance of noninstrumental factors (Desmet 2002; Norman 2004; Ortony et al. 2005). These concepts are assigned to the three levels of interaction. If mobility behavior is essentially (co)determined by noninstrumental, symbolic, and emotional factors, then these must be considered in the design of intermodal mobility systems. Here, the goal is to enable a smooth and satisfying interaction during usage and to achieve a positive (emotional) evaluation that has a meaningful effect beyond the usage act itself. Consequently, meaning is formed and formulated through the design.

01 The research project »Infrastruktur—Design—Gesellschaft« (2018 to 2021) was funded by the Landes-Offensive zur Entwicklung wissenschaftlich-ökonomischer Exzellenz (LOEWE) in the German Federal State of Hesse with the following lead project partners: the University of Art and Design in Offenbach (design, consortium lead), the Frankfurt University of Applied Sciences (transportation planning), Goethe University Frankfurt (mobility research), and the Technical University of Darmstadt (media and communication technology/architecture).

02 Originally developed in the 1990s in the context of human-computer interaction (HCI) in parallel with computer science and product design, the term human-centered design defined a process for involving users in the design process and the problems involved with computer display work. In economics, human-centered design is also discussed as a component of management techniques (design thinking).

03 Smartphones (and other wearables) are technologies commonly used today to mediate between the informational and physical environments; what specific requirements for the design of such user interface (user interface design) will not be discussed separately. Although information available while on the move is increasingly being requested in a progressively more complex manner (for example, via gestural or mimic and acoustic control mechanisms), it still forms a largely delimited space that must be operated via input media. Nevertheless, it is necessary to correlate the information provided digitally with the information in the physical space in order to achieve as clear an understanding as possible among users; that requires coherence in information design at both the digital and analog levels.

04 The workshops were led by Kai Vöckler, who prepared and conducted them together with Julian Schwarze and Janina Albrecht. Kai Dreyer, Peter Eckart, Anna-Lena Moeckl, Thilo Schwer, and Knut Völzke were also involved in the workshops.

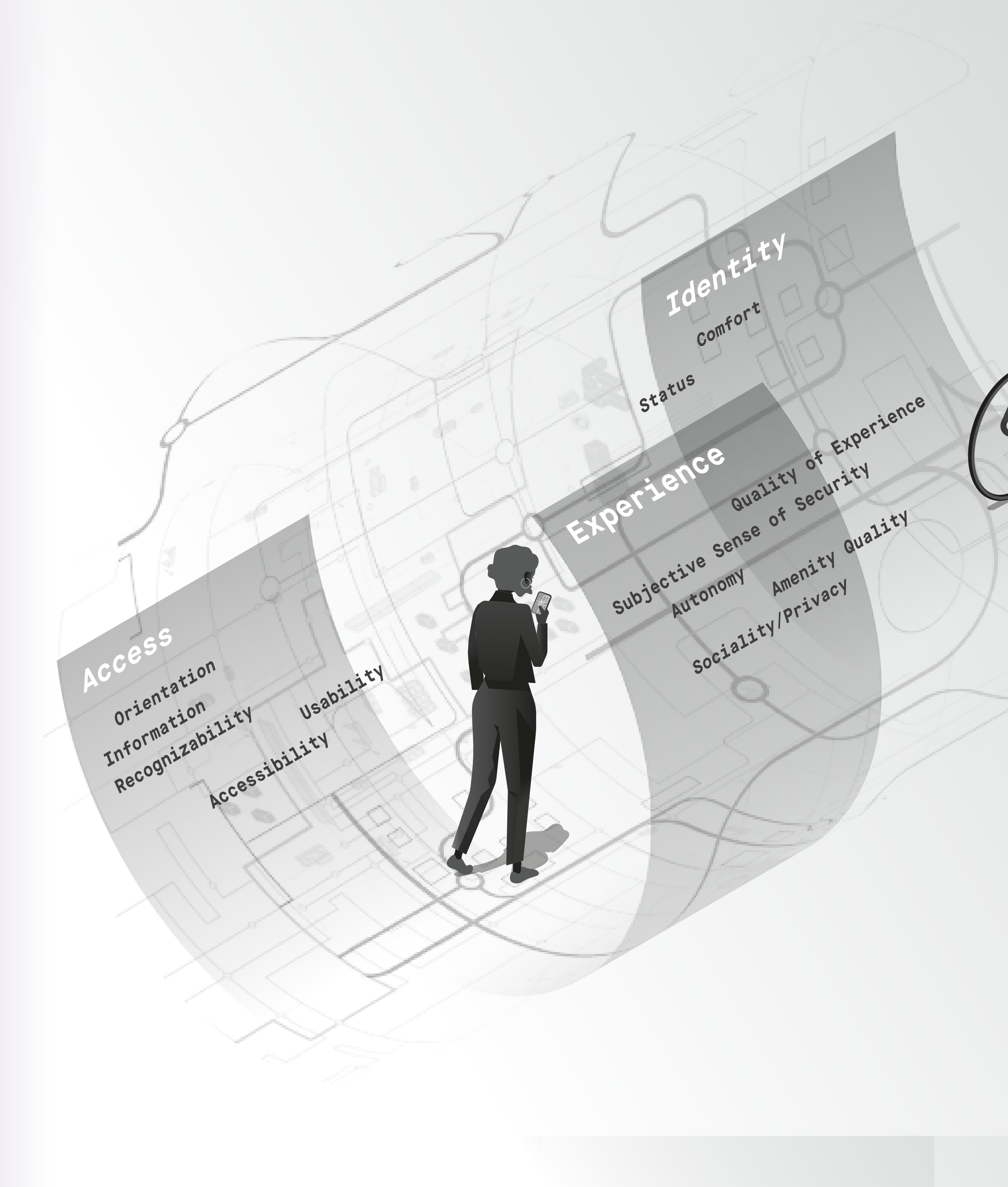
Identity
Comfort
Status
Experience
Quality of Experience
Subjective Sense of Security
Autonomy
Amenity Quality
Sociality/Privacy
Access
Orientation
Information
Recognizability
Usability
Accessibility

Fig. 1 Offenbach Model: Diagram of user interaction with an intermodal mobility system together with the concepts guiding its design, which have been assigned to three interlinked areas of interaction (Source: DML/HfG Offenbach; concept: Peter Eckart, Julian Schwarze, and Kai Vöckler; graphics: Beatrice Bianchini and Ken Rodenwaldt)

The Offenbach Model: Areas of Interaction and Guiding Concepts

Access

The basic prerequisite for the utilization of a publicly accessible intermodal mobility system is that access is functionally enabled (for all users). This concerns recognizability and accessibility (barrier-free access), the provision of necessary information, the design of orientation elements, and the usability of the objects that people interact with. It is the goal of the design to ensure a trouble-free process that can be mastered with minimal cognitive effort. This includes, for example, a comprehensive information and guidance system, recognizable links and connections, and ticketing (digital and analog). Additional factors are the structuring of circulation spaces and the positioning of spatial elements that provide orientation, as well as operational elements that can be understood intuitively.

Recognizability It is essential to design the entire intermodal, environmentally friendly mobility system (with its different interlinked mobility services and resultant variety of spaces along a route) as a recognizable coherent structure (coherence of design). Recognizability is a fundamental prerequisite for establishing symbolic meaning (see the Identity section below). Significantly, this also includes the transparency of the data that enable digitally supported interactions, which must be communicated in a recognizable way—through the link to physical space.

Accessibility Inclusive mobility system design also permits people with physical and cognitive impairments to use the system without assistance (accessibility). This applies particularly to aspects of traffic safety and routing during use. Consequently, it is necessary to design visual, acoustic, and tactile information according to the two-senses principle. An inclusive design also takes into account, in the sense of »design for all« (universal design), the effects of age, educational level, and cultural familiarity, up to and including economic restrictions on access.

Usability focuses on the actual usage situation, on the effectiveness and efficiency of use, with the objective of ensuring that mobility processes run smoothly. This is to be achieved primarily through the self-explanatory character (intuitive use) of the system. Therefore, comprehensibility that requires minimal cognitive effort is a central design objective. Usability, in relation to specific practical functions, is one of the operational prerequisites of usage. Ergonomic aspects play a central role in this context by optimally supporting use and minimizing strain or disturbance. An important prerequisite for the usability of mobility systems is traffic safety, which must be appropriately conveyed through design (see the above section Accessibility).

Information Comprehensive analog and digital information linking the various mobility services and spaces (information and routing systems; pictorial and written symbols such as pictograms, maps, written and numerical information) is the basis for intermodal and multimodal mobility. In addition to information on mobility services, this also includes information on routing, travel times, and distances (including travel costs, if applicable). Among these are signs indicating escape routes, alarm devices, and hazard markings, which must all be designed in a clear and comprehensible manner to ensure traffic safety. In addition, there is further information on useful facts such as spatial location (site plans), as well as on additional services (e.g., gastronomy), and experiences to be had. Mobility-related information must be clearly differentiated from additional information (such as advertising or entertainment options) for the sake of the recognizability needed for mobility purposes.

Orientation Wayfinding is a central component of orientation, which on the one hand is supported by an information and wayfinding system (see the section Information), and on the other hand should occur intuitively when interacting with the space (as flow), as a reflection of usability. This corresponds to clear spatial organization and routing via space-defining architectural elements together with objects positioned to provide orientation in conjunction with posted information (routing systems). This includes the formation of visual reference points (landmarks), which guide action and lead to the nodes, where decisions on further routing are necessary (see Schwarze et al. in this volume). These orientation elements enable intuitive wayfinding and hence the linking of different mobility options.

Experience

Socioemotional factors are essential for positive mobility experiences and pertain to the requirements for (»subjective,« i.e., perceived) safety, experiential and amenity quality, and privacy and social interaction. Design measures can, for example, provide for the visual control of a space, thus creating a sense of security through the establishment of visual relationships and appropriate lighting. However, these can also create spaces for retreat as well as interaction within the spatial organization. In addition, the design of objects that are essential for the stay (waiting times), such as seating and leaning options, convey a sense of quality and thus of value through their materials and design language. It is also important to create experiential quality through attractive visual relationships among contextual features in the interplay of the spatial configuration, objects, and signs. Last but not least, the goal is to create positive self-awareness (self-positioning in terms of spatial perception) and thus a sense of self-efficacy (autonomy) within the flow of barrier-free and intuitive use. Mobile access to the internet also influences the sense of security and location (sense of direction and self-positioning). Accordingly, the association with real space (recognizability) should be designed in conjunction.

Amenity Quality A sense of well-being is strongly affected by the intrinsic value of the environment as conveyed through its design, which is experienced as being purposeful when its usage is stress-free. Essentially, this involves the design modification of functional requirements to ensure amenity quality in transport, transfer, and waiting areas (weather and noise protection, seating and standing areas, lighting, and materials), with the overall atmosphere of the space, objects, lighting, and information reflecting their inherent value.

Quality of Experience Stimulating mobility experiences contribute to positive emotional assessment. Thus, the design focuses on communicating and accentuating the experiential qualities that result from movement in physical space. The joy of locomotion and being on the move can be designed in relation to the usage context, for example, through the formulation of visual relationships to the surroundings. Or, by arousing interest and curiosity in the process itself as well (by making it possible to experience the rhythm of locomotion).

Autonomy The feeling of freedom engendered by deciding for yourself which route and mode of transport to take strongly influences the emotional assessment of the mobility experience. Here, the decisive factor is designing a process that is as free of disruptions and as clearly recognizable as possible, and thus comprehensible. Self-efficacy is also experienced through positive self-perception, in that finding your own way is facilitated by an appropriately designed spatial experience. In this context, the connection to digitally available information is to be designed for as well, in respect to operational choices, processes, and self-positioning.

(Subjective) Sense of Security Design interventions exert considerable emotional impact on the subjective feeling of safety (such as fear of harassment or criminal assault). For example, the design and illumination of the mobility space can create visibility and thus provide an overview, which allows for visual control of the space. This also includes the formation of spatial areas of retreat and protection (»back protection«) and visible means of avoidance and escape. A design element such as lighting, for example, can exert a calming effect through a warm light temperature. Cleanliness, which is important for the subjective feeling of safety, can also be supported in terms of design by appropriate materials, although their value and the symbolically conveyed appreciation associated with them must also be put into perspective. The digital expansion of personal action space in addition offers a variety of possibilities for conveying confidence in the safety of the mobility process, which also applies to questions of traffic safety (as part of the information about the process and possible disruptions).

Sociality and Privacy Sociality and privacy are two mutually dependent needs that are to be treated differently in terms of design, which consequently must be brought into relationship with one another. On the one hand, there is the need for social interaction beyond the mobility function, which enables a sense of community. This means a communication-oriented spatial organization that favors self-determined social interactions (such as appropriately positioned seating). In principle, there is also the option of allowing for digitally supported communication between actors in usage contexts. On the other hand, it is essential to consider the need for privacy and to create opportunities for spatial separation and demarcation (distances).

Identity

A coherently developed design (including in relation to digitally available information) fosters a sense of well-being when in use, which conveys a feeling of respect (comfort) in its emotional impact. The symbolic effect of the design language conveys meaning that can be engaged with. In this way, a positive experience of social positioning is made possible (status). Both aspects with their symbolic significance must already be considered in the actual design. Together, they help users identify with the mobility system. In particular, the public character of the intermodal mobility system requires a symbolic design that articulates its social significance.

Comfort The quality of the design in its aesthetic effect, in concert with the interaction of forms, colors, materials, light and spatial design, communicates an overall appreciation of user needs. This space is permeated by digital (and increasingly personalized) information, which must be suitably incorporated into the general experience. This essentially concerns the symbolic-emotional effect of the mobility system in use, which is experienced as appreciation.

Status The design of the mobility system conveys symbolic meaning. What does an intermodal, ecologically beneficial system stand for? Important themes to be expressed through the design are environmental friendliness, innovativeness, and sustainability. Here, sustainability means durable design that is not oriented to commercially exploitable, short-lived fashions, but rather is committed to a public design language that serves the common good. As a central part of public life, the design of an essential public mobility articulates its significance for society as a whole. In this way, social recognition is also conveyed to the users, which results from participation in this form of progressive and sustainable mobility.

Elaboration of Key Terms in Relation to Mobility Research and Transportation Planning
In principle, the importance of symbolic-emotional influences on mobility behavior has been recognized in mobility research as well as in urban and transportation planning, but it has not yet been adequately systematized and modeled in a way that could guide design practice. The Offenbach model intends to accomplish this in a first step, while remaining mindful of the lack of empirical validation (see Schwarze et al. in this volume).

The modeling here was based on existing models of interactive design, which are grouped together in design research under the term *user-centered design*, an approach that combines utility and usability (Norman 1988). This was subsequently expanded to *user experience design*, which focuses on positive user experience through the design of digital and analog artifacts, while broadening this to incorporate emotional factors (Norman 2004). The user experience also includes the effects that a product has on users before they use it (anticipated use) and after they use it (identification with the product). Accordingly, it also refers to emotional and aesthetic qualities (from the user's point of view) and not only to functional characteristics (Hassenzahl and Tractinsky 2006). The concept has already been standardized with ISO 9241-210 as a norm for the human-centered design of interactive (technical) systems, whose terms were accommodated insofar as they concern the direct interaction with the product and not, for example, organizational-technical or even resource-related aspects such as the question of the efficiency or effectiveness of the system (ISO 9241-210: 2019). For the Offenbach model, other terms of user experience design were also adopted (Morville 2004; Hassenzahl 2018). The starting point is user needs, which are to be communicated within a usage context (with its technical, physical, social, cultural, and organizational components). However, the selection is limited to the usage process (interaction with the mobility system) (see also Desmet and Fokkinga 2020 with their further development of Maslow's hierarchy of needs and a redefinition of the guiding concepts in a meta-analysis of the relevant psychological literature). Yet there is still no agreement within design research as to which conceptual system is considered to be the most viable. In addition, the various definitions of user experience design, which are not always systematically elaborated, also refer to different contexts of use (interactive technical or analog products). For the terms used in the modeling process, see the matrix of terms discussed (↳Fig. 2).

Social science mobility research into the factors influencing the use of transportation focuses on, among other things, attitudes toward transportation (Anable and Gatersleben 2005; Steg 2005; Hunecke 2006). This attitude reflects the subjective stance, mixing rational and emotional factors. In addition, attitude indicates an associated behavioral tendency. However, here attitude relates to the use of transportation (and the implicitly linked evaluation of the transportation infrastructure or the mobility system). The psychological construct *attitude* is operationalized differently in the studies considered; for example, a distinction is made between instrumental, affective, and symbolic factors (Steg 2005), or the noninstrumental factors are summarized as symbolic-emotional factors (Hunecke 2006; Haustein in this volume). Structurally, this also corresponds to the division into the three areas of interaction in the Offenbach model, with the instrumental (*access*, the practical dimension) as well as the noninstrumental factors of influence (*experience*, the aesthetic dimension in its affective impact, as well as *identity* as the symbolic dimension). However, classifying them into instrumental and noninstrumental factors has proven to be difficult, as a number of terms cannot be clearly assigned to either category (Pripfl et al. 2010; Busch-Geertsema 2018). For example, autonomy can be classified as independence in the sense of self-efficacy as part of the symbolic-emotional factors or it can also be defined as freedom in terms of the private availability of a means of transport playing an instrumental role. Overviews that systematize the developed terms in a summary manner are therefore confronted with the problem of having to consider partly conflicting definitions of the same terms. Nevertheless, even with different classifications and limitations, there is a large overlapping of terms that may be identified as being significant for mobility activity (see the meta-analysis by Pripfl et al. 2010; Busch-Geertsema 2018; ↳Fig. 2). For application-oriented design research, it is sufficient to be aware of the factors that influence attitudes toward the use of transportation (and thus indirectly also mobility actions) and to consider them as critical user needs in modeling. In doing so, all factors were excluded that cannot be directly addressed in terms of design. This applies, for example, to important influencing factors such as the availability and reliability of the mobility services provided, which primarily affect the planning and organization of personal mobility. In this context, however, it is important for the design to convey the information to users in a comprehensible way. One example here is travel expenditure. From the user perspective, information about travel time as a fundamental consideration (the time required to cover a distance) must be available when choosing between different mobility services, which is therefore considered under the guiding concept of information, as are the factors mentioned above. Yet, time also plays an essential role in the quality of the experience, since the experience of a *flow* is to be understood qualitatively as a trouble-free, seamless flow of locomotion.[05] Influencing factors such as environmental awareness (which we instead understand as a social norm) as well as health (as a personal norm) were not taken into account, since these can or should be part of the symbolism to be formulated in terms of design, but certainly do not apply to all users.

In transportation planning, the importance of design has been neglected so far (Hofmann 2019). In English-language publications on the topic of design, planning and engineering issues are usually dealt with from an instrumental point of view, such as in the planning of road layouts and alignments, which do not adopt a design perspective based on user needs (Cervero and Kockelman 1997, who introduced in their frequently cited article the planning-relevant »3 Ds«: density, diversity, and design). Emotional and symbolic aspects are scarcely considered in the planning of public transport facilities (Hofmann 2019). Studies and manuals on the planning and design of multi- and intermodal mobility, in particular on mobility stations and interchanges, point out the need for design—for example, with regard to their urban spatial impact. However, this is essentially limited to functional aspects such as recognizability and accessibility, although the symbolic impact in the urban spatial fabric is still discussed to a limited degree. However, no clear recommendations are made, nor is there a systematic elaboration of the design requirements (BBSR 2015; Zukunftsnetz Mobilität NRW 2015). The guidelines of the Road and Transportation Research Association (Forschungsgesellschaft für Straßen- und Verkehrswesen—FGSV) name important design factors in the planning and design of local public transport connection facilities (FGSV 2009), such as quality of experience, which is also addressed in its symbolic effect (in the use of high-quality materials expressing appreciation, which we assigned to comfort) as well as with regard to its public character (in our view, part of sociability as the need for social interaction and proximity). In addition, the perception of security (subjective security) and the associated need for privacy, which is important for social acceptance, are also mentioned. The FGSV (2009) also considers important functional requirements such as barrier-free accessibility and the importance of information and orientation as a prerequisite for access when using transfer points. It highlights the fact that these are generally central places in urban life, offering aesthetic quality and symbolic impact that provide a means of identification. These central factors were incorporated into the Offenbach model and have been consistently developed conceptually from the user perspective. However, the FGSV does not differentiate between management activities (such as cleaning services), urban and traffic planning (such as compact building structure, weather protection, and direct routing), and design activities (architecture and design), which convey the functional requirements in a user-centered (and inclusive) manner while also significantly contributing to the emotional and symbolic impact of the mobility system.

In conclusion, it can be said that a sufficiently systematic and conceptually defined modeling of the requirements for the design of intermodal, environmentally friendly mobility systems has not been undertaken to date. Based on the findings of mobility research and transportation planning, the Offenbach model is presented for discussion here as a scientifically derived design proposal for structuring design requirements in the context of public mobility.

Outlook: The Design of Future Interaction Spaces (Post Human-Centered Design)

Digital transformation has fundamentally changed mobility space. This concerns not only the currently possible, expanded, and personalized options for user engagement through the mobile internet, but also the future development of the mobility system into an adaptive and responsive system increasingly controlled by artificial intelligence. Through the development of a technological system that is data-based, operates in real time, is decentralized, personalized, and self-optimizing, the transportation system will become dynamic through the use of algorithms and thus adapt to user behavior in an anticipatory manner. »Intelligent environments« will emerge that not only provide options for user action, but also adapt services individually in advance on the basis of available personal data, thereby optimizing the user's ability to act (Eckart and Vöckler 2022a). This transforms the interface between humans and the (artificial) environment as well as the technical system that is interwoven with it. Technology is no longer a tool that enhances the human capacity to interact with the environment, but rather information and communication technology creates new environments within the informational penetration of physical space. But this means that the acting human is no longer the focal point in the environment—they are deprived of their »uniqueness« (Floridi 2014). And this is despite the fact that the digital penetration of the environment will allow it to be adapted to individual needs in ways that could hardly have been imagined previously. For design and design theory, this also requires a reformulation of the human-centered approach such that it becomes an ecological one, which goes beyond the anthropocentric to consider the coaction of things (Morton 2018).

The design of a »post human-centered interface« merges with the material environment and consequently disappears as an identifiable interface (Weiser 1991), thus requiring mediation of this new arrangement through design (Redström and Wiltse 2019). These ambient intelligences thus act independently via their material presence as well. In order to convey their performative qualities, a theoretical reconceptualization of affordance (and indicating functions) through design will be needed (Jensen et al. 2016). In doing so, the interaction space itself, the relationships created within it, and its digital linkages will have to be designed and thus mediated—also in the sense of empowering users (Easterling 2016). In short, the artifacts that will be interacted with in the future can no longer be seen as being closed, or fixed, nor as being set apart from oneself. This will require not only the development of new cultural techniques, but also their creative mediation. The decisive factor here will be that it is not so much the »what,« the object—which does not disappear, but is part of the expanded interaction space in its interface function—but the »how,« that is, the rules, connections, and protocols that must be communicated (Easterling 2021). This is also a political question: the design of digital infrastructures must preserve the personal rights of citizens and should ultimately facilitate informational self-determination (Eckart and Vöckler 2022b). As yet, no theoretical design concepts guiding design practice have been created for this emerging development—this will have to be addressed in the future. However, we think that the systematic recording and modeling of design parameters presented here can help to clarify the design challenges and serve as a basis for further research. Against the background of

05 A good example is the Cykelslangen bicycle bridge in Copenhagen with its curved path, which is totally pointless from a functional standpoint (increased travel time), but allows for a memorable mobility experience offering varying, attractive vistas; it has thus been accepted with great enthusiasm (and at the same time has made a strong symbolic impact as an iconic symbol of environmentally friendly mobility).

Pripfl et al. 2010 [1]	Busch-Geertsema 2018 [1]	Desmet and Fokkinga 2020 [2]	Hassenzahl 2018 [2]	
User-friendliness*			**Usability**	
Travel time*	**Time***			
Travel costs*	**Money***			
Comfort* (travel comfort, transport option, weather independence)	**Weather***			
Availability*	**Flexibility***			
Accessibility*	**User-friendliness***			
Reliability*	**Reliability***			
			Trust	
Autonomy**	**Autonomy*****	**Autonomy**	**Autonomy**	
		Competence	**Competence**	
		Impact		
Status**	**Status******	**Recognition**	**Meaning**	
		Relatedness		
Experience**	**Experience*****	**Stimulation**	**Experience**	
			Surprise	
Privacy**	**Privacy*****		**Sense of security**	
Freedom from stress**	**General sense of well-being*****	**Comfort**	**Sense of well-being**	
	Relaxation***		**Problem avoidance**	
Security/safety**	**Security/safety****	**Security**	**Perceived security**	
Environmental awareness**	**Environment****	**Morality**		
		Purpose		
	Health/fitness**	**Fitness**		
		Beauty		
		Community	**Proximity**	
* Purposeful-rational factors	* instrumental – direct			
** Social-emotional factors	** instrumental – indirect			
	*** affective			
	**** symbolic			
[1] Factors influencing attitudes toward transportation use				
[2] User needs in general/when interacting with products				
[3] User needs when interacting with digital products				
[4] User needs when interacting with public transport facilities				

DIN EN ISO 9241-210: 2019 [3]	Morville 2004 [3]	FGSV 2009 [4]	Correlation in the Offenbach Model
Usability	**Usable**		**Usability****
		Reachability	**Information***
			Information*
		Information and orientation	**Information*and orientation**
Context of use		**Multifunctionality**	**Amenity quality****
Efficiency			
	Findable	**Accesses (recognizability)**	**Recognizability***
Accessibility	**Accessible**	**Accessibility for people with movement limitations/ transport safety**	**Accessibility* (transport safety)**
Effectiveness	**Useful**		**Usability****
Satisfaction	**Credible**		**Status*****
			Autonomy**
			Autonomy**
	Valuable	**Identification (image and identity)**	**Status*****
User experience			**Quality of experience****
			Quality of experience**
			Privacy/sociality**
			Amenity quality**
		Social acceptance/subjective sense of security	**Subjective sense of security****
	Desirable		**Comfort (valuation)*****
			Sociality/privacy**
			* Access
			** Experience
			*** Identity

Fig. 2 Matrix of critical terms in the selected literature. Comparability is limited because the analyses listed refer to different contexts. The matrix of terms used served as orientation in the development of the guiding terms to identify overarching patterns. (Source: DML/HfG Offenbach; Kai Vöckler)

the future dissolution of input interfaces and the emergence of personalized »intelligent environments,« the model proposed here will have to be further developed towards the design of an informationally enhanced »Human-Environment Interaction« (Encarnação et al. 2015), in which humans, the environment, and technical systems will enter into a new relationship. This must be conveyed through design in order to facilitate understanding and create meaning.

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Shaping Mobility through Design?

A Transdisciplinary Mobility Research Perspective

Andreas Blitz, Martin Lanzendorf, and Hannah Müggenburg

For the past few years, the influence of spatial design on individual mobility behavior has been a focus of empirical mobility research. The structures and objects generally encompassed by the term *built environment* cover a broad spectrum, ranging from smaller components such as streetlamps and traffic lights, to the construction of entire street networks, neighborhoods, or cities (Lawrence and Low 1990; Handy et al. 2002; Smith et al. 2017). Much research draws on the spatial and structural characteristics described by Cervero and Kockelman (1997) as »density« (concentration of development, population, and jobs), »diversity« (mixed use of housing, work, utilities, educational and recreational functions, as well as mix of building types), and »design« (structure and layout of the street network and spaces, presence of pedestrian and bicycle infrastructure). These dimensions, known as the »3 Ds,« are understood to be key determinants of the distances traveled and consequently of the choice of transport mode and individual mobility behavior (Ewing and Cervero 2010; Busch-Geertsema et al. 2020). Accordingly, the main consideration here is the practicability of mobility options in relation to the expenditures associated with mobility (Handy 2018; Bohte et al. 2009).

Less attention has been paid to characteristics of the built environment that go beyond this, such as aesthetic features. Therefore, the question of how mobility spaces as a whole affect mobility behavior often remains open.

In this essay, we would like to address the problem by adopting a broader, transdisciplinary perspective that views mobility behavior not only in terms of objectively measurable travel expenditures, but also on the basis of individual perceptions and evaluations of the design aspects of public space. A central research method to this end is the theory of product language, which comes from design research and will be discussed in more detail in the next section. This theory describes the effect of the built environment on the individual, based on various functions. This is followed by an overview of prior research findings on the effect of these functions on mobility behavior. We will then show how transdisciplinary, empirical mobility research can be implemented by involving practitioners, using the example of a research project that has already been carried out. This essay concludes with some final remarks on possible further research.

An Expanded Understanding of the Impact of the Built Environment: The Theory of Product Language Applied to Mobility Research

In his work on product language, Gros (1972) distinguishes three main functions in the relationship between humans and objects: the practical, the aesthetic, and the symbolic—subsequently also referred to as the practical, formal aesthetic, and semantic functions (Gros 1983). The practical function refers to the execution of an object's purpose and its use. These include properties such as functionality, operability, practicality, safety, durability, and efficiency, focusing primarily on objective-rational characteristics (Zeh 2017). By contrast, the other two functions of an object are mediated by individual perceptions or sensory impressions (Gros 1983). In this context, the aesthetic function refers to design qualities that are perceived as stimuli independently of possible attributions of meaning. These include basic features such as shapes, structures, colors, materials, or the formal aesthetic manifestations of complexity and order (Mareis 2014; Steffen 2000). The symbolic function as the semantic dimension of objects describes their communication of meanings and information (Zeh 2017); Gros (1983) distinguishes between symbols and indicators. Symbols point to contexts that go beyond the actual characteristics of the object. For example, they evoke associations and ideas of specific cultural, social, economic, or ecological meanings (Bürdek 2005; Steffen 2000). Indicators, on the other hand, point directly to the purpose, status, and operation of an object, thus highlighting its practical function, for example, by means of switches and labels (Steffen 2000; Gros 1983; Zeh 2017). When all design functions are taken into consideration, this allows for a comprehensive view of the perception and evaluation of objects and thus can also provide a clue as to their effects on the individual.

Linking this theoretical design concept with social science and urban planning approaches results in new ideas on mobility research and the promotion of sustainable mobility. Although the concept of design functions was originally focused on product design, it can be transferred to the urban and mobility spheres, for example to individual objects such as plantings, or to entire mobility systems and spaces (Blitz and Lanzendorf 2020; Vöckler and Eckart 2020). For instance, mobility stations and transfer points in public spaces can convey symbolic and aesthetic impressions in addition to the practical functions related to the use of transport modes, and thus be associated with positive or negative perceptions and emotions (Hofmann 2018; Knöll et al. 2014; Gehl 2010).

The Promotion of Nonmotorized Mobility through the Design of Urban Spaces: Findings to Date on the Effect of Design Functions

In considering objectively measurable spatial and temporal accessibility, the focus of previous research has been primarily on the practical function of mobility spaces (Blitz and Lanzendorf 2020). It has been shown that a high density of development, population, and jobs, combined with a high degree of mixed land use, a seamless, dense street network, and proximity to destinations, results in a reduction in the use of private cars and favors bicycle and pedestrian travel (Brownson et al. 2009; Newman and Kenworthy 2006; Buehler 2011; Ewing and Cervero 2010; Holtzclaw 1994; Saelens et al. 2003). The reduction in travel distances to everyday activity locations resulting from the aforementioned factors—that is, the creation of a compact city of short distances and the concomitant reduction in individual travel expenditure—is cited as a crucial reason for these relationships (Banister and Hickman 2006; Næss 2012; Van Wee 2002). In addition, many empirical studies indicate that the availability of dedicated bicycle and pedestrian infrastructure contributes to the safety and convenience of nonmotorized mobility. This includes such features as separate pedestrian and bicycle lanes, crosswalks, and bicycle parking facilities (Larco et al. 2012; Mitra et al. 2015; Gunn et al. 2014; Kamargianni 2015; Moudon et al. 2005; Saelens et al. 2003; Buehler and Dill 2015).

There has been relatively little research devoted to the effect of aesthetic features on individual mobility. Some studies suggest that the design of urban spaces with green areas and trees not only leads to the beautification of the cityscape, the enhancement of amenity quality, and the improvement of the urban climate, but also increases the inclination toward active mobility (Wang et al. 2016; Giles-Corti et al. 2013; Mitra et al. 2015; McCormack and Shiell 2011). Subjective perceptions of attractive architecture (Milakis et al. 2017), of cleanliness and orderliness in public spaces (Blitz 2021), or of environments seen to have overall aesthetic appeal (Giles-Corti et al. 2013; Koohsari et al. 2013) also achieve a similar effect. Other research also highlights the positive influence of street and square designs that provide orientation and clarity (Rybarczyk and Wu 2014; Hajrasouliha and Yin 2015). Gehl (2010) further emphasizes the importance of proportions in public spaces being aligned with human perception and visibility. For example, open spaces that are too large would make it difficult to get an overview of what is happening.

Symbolic features of the mobility-related design of the built environment include signage, markings, and signals in the road space that function as indicators. Even though clearly perceptible markings are said to play an important role in the design of safe traffic areas, especially at intersections, studies on their influence on pedestrian and bicycle mobility have been few (Buehler and Dill 2015; Wang et al. 2016). Winters et al. (2010) were able to show that the presence of bicycle-related road markings and signage at the destination increased the likelihood that people would use a bicycle instead of a car. Mitra et al. (2015) indicate that stop signs at intersections increase pedestrian safety. In addition, symbolic features also include symbols that can evoke particular associations with objects or spaces. For example, adequate street lighting or surveillance cameras in public spaces often convey a general sense of safety (Mitra et al. 2015), which can be considered a key factor in the willingness to bike or walk in urban spaces (Koohsari et al. 2013; Battista and Manaugh 2018; Giles-Corti et al. 2013; Blitz 2021). By contrast, individuals from neighborhoods that create an overall subjective impression of a strong car orientation are less likely to engage in non-motorized travel (Frank et al. 2015).

A Methodological Approach to Transdisciplinary Mobility Research

The research results to date show that individual mobility behavior cannot be understood solely on the basis of the practical aspects of various mobility options. Aesthetic and symbolic functions of mobility spaces, which are prone to subjective judgements, also play a role, yet they have received comparatively little attention so far. While the observation of practical characteristics alone, such as distances or travel times, is often limited to secondary data on built structure and transportation usage, a transdisciplinary research perspective results in an empirical approach that is more closely related to the individual. In contrast to simply recording the location and structure of individual elements within the built environment, the consideration of individual perception of mobility spaces is of central importance. Within the framework of a research network, this could be achieved through an exchange between different disciplines using various methods, such as interviews, written surveys, focus group discussions, or the technical recording of psycho-physiological parameters (including eye-tracking).[01] Furthermore, the research was characterized by exchange and cooperation among different partners from the fields of urban planning and mobility services, which facilitated the actual implementation of individual research projects in urban space.

One example of transdisciplinary research on the design of an urban mobility space is the work focused on cycle streets in Offenbach am Main (see Albrecht et al. in this volume). The social science methods of written household surveys (Blitz 2020) and focus group discussions (Baumgartner et al. 2020), which were chosen to investigate individual perceptions, were supplemented in terms of content and method by approaches from design research. Firstly, this was done by considering all three design functions. For example, the household survey covered perceptions of the practical features, such as functionality and safety, as well as aesthetic features, such as the aesthetic effect in the cityscape, and symbolic characteristics, such as markings and signage for cycle streets. Secondly, various design concepts for cycle streets were integrated into the survey and focus group discussions in the form of graphic illustrations. These were created in the context of a design project at the HfG Offenbach University of Art and Design in collaboration with the mobility research group of the Goethe University Frankfurt and the Offenbacher Projektentwicklungsgesellschaft, who is responsible for the practical implementation of the cycle streets (Albrecht and Eckart 2020). In this way, both social scientific findings on mobility behavior and practical planning requirements were integrated into the designs. On the one hand, the integration of the designs made it possible to learn more about the extent to which perceptions can be assessed by means of graphic illustrations. On the other, conclusions on design improvements could be derived from the empirical results of the survey. These were considered in the implementation of additional cycle streets in Offenbach with the aim of increasing their recognizability for users. ↳Fig. 1 shows an excerpt from the household survey, which recorded the perception and impact of an already realized cycle street as well as additional cycle street designs.

The Transdisciplinary Perspective as a Basis for Further Research

As the example of the research work on cycle streets in Offenbach am Main demonstrates, it is possible to achieve added value for mobility research as a whole through exchange and cooperation

01 The research project »Infrastruktur—Design—Gesellschaft« (2018 to 2021) was funded by the Landes-Offensive zur Entwicklung wissenschaftlich-ökonomischer Exzellenz (LOEWE) in the German Federal State of Hesse with the following partners: the HfG Offenbach University of Art and Design (design, overall management), the Frankfurt University of Applied Sciences (transportation planning), Goethe University Frankfurt (mobility research), and the Technical University of Darmstadt (multimedia communications; architecture/urban design).

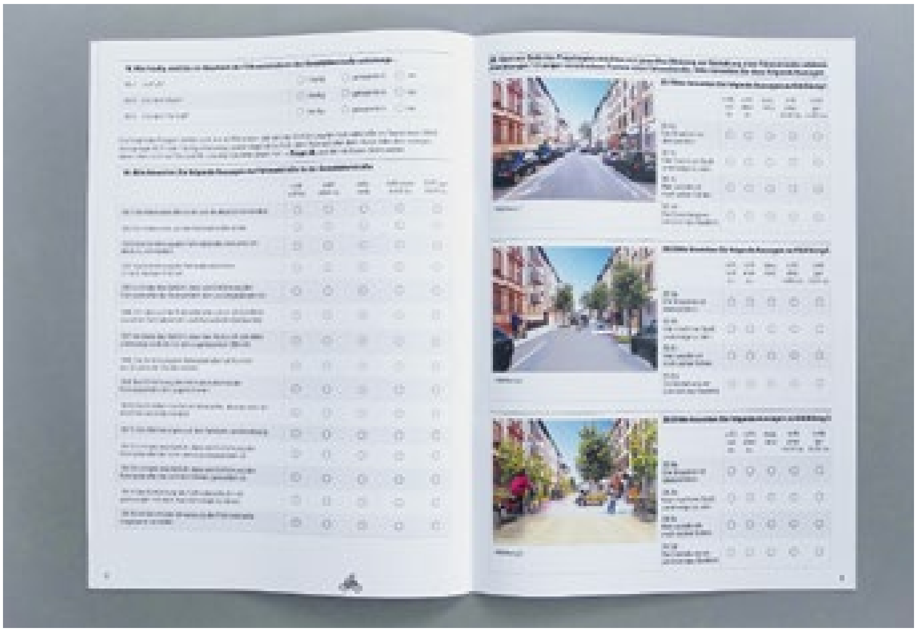

Fig. 1 Excerpt from the survey: »On the Move in Offenbach« (Source: Janina Albrecht)

among the social science, design theory, and urban planning disciplines, as well as with relevant practitioners. Thus, at the level of theoretical foundations, empirical methods, and practical implementation, various findings were linked to form a transdisciplinary perspective that contributes to a better understanding of individual mobility behavior; in addition, this also points to new approaches for scientific research and practical measures for mobility design. For example, the effect of aesthetic and symbolic features could be identified, a factor which should also be considered in future research alongside practical functions. In addition, this research also yields promising starting points for the design or redesign of urban spaces, which have scarcely been considered so far, as a means of making walking and cycling more attractive. These include, for example, green areas or elements that impart a sense of security, such as lighting and cleanliness. However, regarding mobility in particular, a number of research gaps can still be identified in relation to the potential aesthetic or symbolic effects of urban spaces, such as in designated public areas or specific walking and cycling infrastructure. Therefore, a transdisciplinary perspective also appears to be useful and desirable when it comes to further research and the implementation of design measures that promote nonmotorized mobility.

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Mobility Design Guide

Making Future Mobility Tangible and Experienceable

Andrea Krajewski,
Sabine Reitmaier,
Kai Vöckler,
and Peter Eckart

In view of global climate change and a simultaneous and constant increase in the volume of traffic worldwide, the strengthening and development of environmentally friendly mobility is understood more and more as a key challenge, not only in terms of transportation planning and infrastructure, but also in relation to society (UBA 2019). To cope with this complex task that demands innovation, it seems sensible to think, plan, and implement mobility within a transdisciplinary context that is both science- and practice-oriented and where design facilitates access to a complex mobility system. This requires a shift in perspective toward a systemic approach, where the innovation process is viewed from within the overall system of environmentally friendly mobility, rather than being focused on individual products and solutions (Rammler 2018: 47). This transformation involves, at the same time, changes in the disciplinary orientation and expertise of those involved in planning and implementation. Today, they must also consider the effects of digitalization in terms of the common good and climate protection, but without designing digitally oriented, enhanced mobility systems on a purely technological basis.

As a new discipline operating within this context, mobility design combines strategic foresight, planning, design, and technological expertise, while opening approaches to complex mobility systems. To convey the relevant content, the »Mobility Design Guide« was produced as a digitally supported, interactive guide based on user-centered design methods. It is intended for decision-makers and planners as well as architects and designers in the mobility sector. It presents them with content related to strategy and design to help them develop new, sustainable mobility systems. This essay introduces the Mobility Design Guide and how it was elaborated.

Mobility design is cross-disciplinary and combines systemic planning, design, and technological expertise, as well as social science knowledge. The actors involved in mobility design come from disciplines such as architecture and design, urban and transit planning, social science mobility research, and information technology. Thus, the Mobility Design Guide needs to provide relevant, accessible interdisciplinary communication tailored to the requirements of the respective target groups.

The Mobility Design Guide is intended to highlight the need for long-term, strategically oriented transdisciplinary planning of current and future mobility projects. Since more complex mobility issues have generally been framed within a purely functional, infrastructural planning context, the guide emphasizes the central role of design (understood as design and architecture and their different disciplinary forms) for the development and advancement of mobility systems. The goal is to use mobility design as a means of achieving widespread acceptance of sustainable, socially responsible mobility. Design per se mediates between systems and people, and renders visions in concrete, experienceable form while facilitating equal access to products. The possibilities for influencing the mobility experience range from process and spatial design to general and personalized information products with their full range of design dimensions (light, color, material, signs). Explaining this cross-disciplinary approach to mobility systems is a key objective of the Mobility Design Guide.

The focus of this essay will be on describing how this guide was developed, conceived, and designed. In this way, the scope of possibilities for design to mediate among diverse bodies of knowledge within a transdisciplinary research context should become clear.[01]

Initial Point of Departure

The shift toward a systemic approach in the planning and implementation of climate-friendly and networked intermodal mobility (Rammler 2018: 47) was the primary point of departure for the concept development. Here, the focus is on the immaterial mobility experience for users, which can only be grasped by taking a holistic view of an intermodal system with its different modes of transport, forms of mobility, and spaces (including their digital extension). Therefore, the concept of the Mobility Design Guide has been consistently developed from the perspective of the users. It seems necessary and advisable to convey this perspective to sensitize the target group of decision-makers, planners, and designers to the special requirements of designing a mobility system that can be utilized in an intermodal fashion. A particular challenge in conveying the perspective of transport users is that not only do they have functional, purpose-driven needs, but they also must be addressed on an emotional, subjective level. To this end, it is necessary to identify, understand, and address the values and attitudes underlying mobility behavior (Hofmann 2019; Haustein in this volume), and from this to determine the influencing factors relevant for design (see Vöckler and Eckart in this volume). Accordingly, this is communicated in, as well as through, the design of the Mobility Design Guide itself.

The objectives of future mobility design can be summarized as follows:

> Mobility design is oriented not toward the individual mode of transport, but instead toward the mobility needs of users … The transferral of personal feelings of freedom, status, value, and security currently associated with an object (the automobile) onto movement (mobility) means that this new form of individual locomotion must offer an experience that is persuasive, sustainable, and perceived positive … The task of mobility design is precisely to make this possible: to pave the way for an ecologically sustainable and socially equitable mobility by giving shape to a climate-friendly, networked, intermodal mobility. (Vöckler and Eckart 2022: 16–17).

In the context of the Mobility Design Guide, a mobility system is understood as the systemic interaction of human and nonhuman participants in transportation—as a form of mobility that arises from the interaction of people, technical systems, things, and information, which is to be designed within an existing or even desired transportation infrastructure.

Requirements for a Mobility Design Guide

A central question for the future use of the Mobility Design Guide was at which point during existing planning and implementation processes could the expertise and knowledge of mobility design have an impact. A widely used planning and implementation process, which is also employed in public administration, is defined in the Federal Chamber of German Architects Fee Scale for Services by Architects and Engineers (HOAI).[02] This was used as a basis for structuring possible applications of the Mobility Design Guide in »User Research.« Qualitative, semi-structured interviews were conducted with participants from all service phases (1–9) of the HOAI.[03] Interviewees came from the fields of architecture, consulting, design, public transportation services, politics, and urban and transportation planning. These interviews demonstrated the significance of the Pre-0 Phase, which is not provided for in the HOAI, as well as Phase 0; thus, additional interviews were conducted with those involved in these phases. In total, twenty people were interviewed.

It became clear that the participants in the Pre-0 Phase, as well as Phase 0 (during which

01 The Mobility Design Guide (https://mobilitydesignguide.org) was developed within the interdisciplinary research network »Infrastructure—Design—Society« (2018–2021), funded by the Hessian »Landes-Offensive zur Entwicklung wissenschaftlich-ökonomischer Exzellenz«, with the participation of researchers from the fields of design, urban design, traffic planning, information and communication technology, and social science mobility research. Project management and creative direction was undertaken by Andrea Krajewski (Professor for Interactive Media Systems, Darmstadt University of Applied Sciences) in collaboration with Sabine Reitmaier (user research, conception, interaction design), Anna-Lena Möckl (conception, content design), Julian Schwarze (conception), Beatrice Bianchini (icons), and Ken Rodenwald (animations). The project was realized together with Maximilian Brandl, Philipp Kaltofen, and Jan Meininghaus.

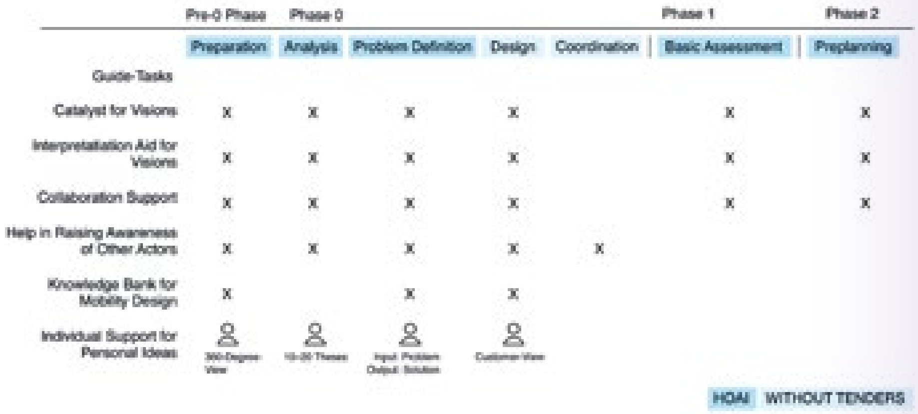


Fig. 1 Interviewee requirements for the Mobility Design Guide following a generic planning process. The procedure illustrated here considers planning processes that do not involve a call for tenders, and includes services described in Phase 0 in the interviews. (Source: Andrea Krajewski and Sabine Reitmaier)

planning specifications are determined and inspiration is sought), represent important audiences for strategically communicating a future-oriented mobility design. Interviewees from the disciplines of design and architecture, who usually work on design planning in Phase 3, explained how Phase 0 is often decisive for the project. After a project has been put out to tender, usually the basic concept or idea cannot really be changed. By including design considerations in Phase 0, the phase when strategic principles are defined and substantive objectives are set, the design requirements are more effectively incorporated in the tenders. Interestingly, interviewees from politics, administration, and business, who have a decisive influence on the Pre-0 Phase as well as Phase 0 itself, expressed the need to be able to learn about inspiring precedent projects as well as forward-looking designs and concepts. This was included as a requirement. Furthermore, it could be deduced from the survey that, in addition to the phases mentioned above, Phases 0 to 2 are also crucial for information regarding mobility design (↳Fig. 1).

The respondents were almost exclusively in favor of a digital, interactive application of the Mobility Design Guide so that they could use it at their own desktop screens. They stated that it would be desirable to be able to incorporate content from the guide into lectures and presentations or to be able to save a personal selection of the material. This application should always be kept up to date and ideally be maintained by several editors who would ensure its reliability and scientific quality (a collaboration among several universities was mentioned as an example). These requirements were addressed in design and elaboration. Following the principles of user-centered design, the findings from the user survey were evaluated and gradually incorporated into the design of the application through workshop-based development. Researchers from different disciplines (design, architecture, social science, and mobility research) participated in the associated workshops. A »value proposition« for the planned application was formulated as a guiding principle for the development process and acted as what is called a »constant companion.«

02 The service phases specified by the German Fee Scales for Architects and Engineers (HOAI): 1: Basic determination with examination of the budget by the client; 2: Pre-planning with cost estimation; 3: Draft planning; 4: Approval planning; 5: Implementation planning; 6: Preparation of tender; 7: Participation in the award; 8: Site supervision—construction supervision, and documentation; 9: Property management.

03 The user research was conducted by Sabine Reitmaier and Andrea Krajewski. All interviews were transcribed, graphically interpreted, and analyzed.

Value Proposition
The Mobility Design Guide is a digital handbook for mobility design. Politicians, urban and transportation planners, as well as architects and designers, are provided with inspiration, models, and research principles to support the planning and realization of future-oriented, socially conscious, sustainable mobility concepts. In contrast to classic reference works, the guide offers arguments for and examples of achieving a transformation in transportation by promoting a new mindset among transportation stakeholders through mobility design.
The guide provides a demonstration and exploration of a user-oriented method for mobility design. Points of departure are the desirable mobility focal points as well as the concrete target formulations and project leverage measures based on these goals. User-centered perspectives are then adopted within a system-oriented approach. This allows for sustainable mobility to be established as a natural transportation option through the design of easy access to intermodal mobility systems and positive user experiences, which results in the affirmation of user identity.

Structure and Composition of the Mobility Design Guide

In interviews with those involved in planning and implementation processes, one idea that often emerged was that the complex topic of new mobility could be approached via an interactive guide from different viewing altitudes as well as by navigating along different access routes: from the big picture to the details, from the abstract to the concrete. This requirement was included as a central objective in the guide's mediation strategy and was set up as a basic structure for the information architecture. In order to provide orientation along access routes and viewing altitudes, the Mobility Design Guide was based on an interactive three-dimensional map of a generic city and its surrounding area that changes with the content. The representation of the content of this three-dimensional map should be seen as an abstracted representation of the users' living space (urban or rural), which serves to position content and orientation within the guide. In this way, the Mobility Design Guide enables users to move from a highly abstract visual level (future visions and their mobility-related configurations) to a concrete, design-oriented level of action (design projects with specific goals). Starting with a view of an entire system, the map view zooms in following the user's gaze as they explore content down to a scenographic, detailed project level. In this way, the Mobility Design Guide deals the need to be able to see, plan, and, in a sense, design a project as a whole picture (↳Fig. 2-4).

The knowledge base is made up of a range of design-based and scientific projects. These are intended to be accessible to specific target groups to suit their various requirements but are interconnected in a context-sensitive manner. The design projects are always linked to a focal point of the future vision. Following strict user guidelines, these projects convey the methods that can be used to design for a mobility objective that is consistently user oriented. They also illustrate the impact of the design features (space, light, color, materials, information systems, typography, activity structuring). By means of interlinking, the design projects are placed in a reciprocal context. In this way, interrelationships among intermodal mobility become visible. The design projects are also linked to the relevant scientific projects. Furthermore, the scientific projects are centrally grouped according to research focus and can be searched by keywords. Thus, the Mobility Design Guide meets the requirements identified during research: inspiration and strategic openness, communication of methodological expertise, and detailed fundamentals (↳Fig. 5).

The Mobility Design Guide has been implemented in an initial functional, user-oriented basic version. It does not yet contain the complete range of functions (such as personalized use). However, it allows the target groups to get closer to the viewpoints, range of possibilities, and visions for mobility design; it also allows them to become intuitively acquainted with the structure of the guide through a process of discovery.

The Mobility Design Guide is also to be understood as a design product itself. The objective of the concept—as with mobility design itself—is to achieve user-oriented, easy access and to

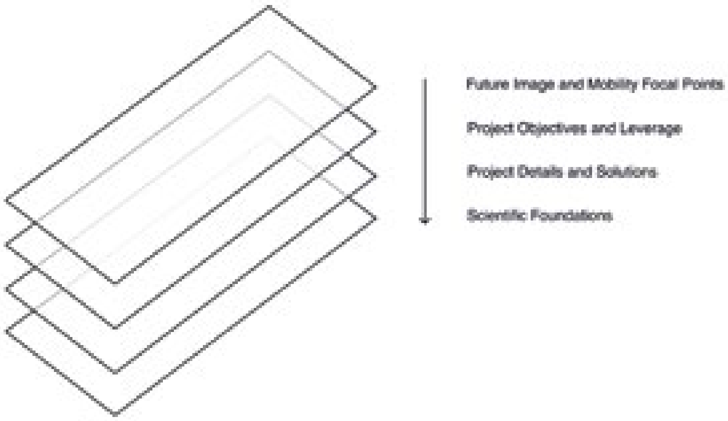


Fig. 2 Moving across the levels at different »altitudes« (Source: Andrea Krajewski and Sabine Reitmaier)

Fig. 3 Map showing zones of different mobility functions (Source: Andrea Krajewski and Sabine Reitmaier)

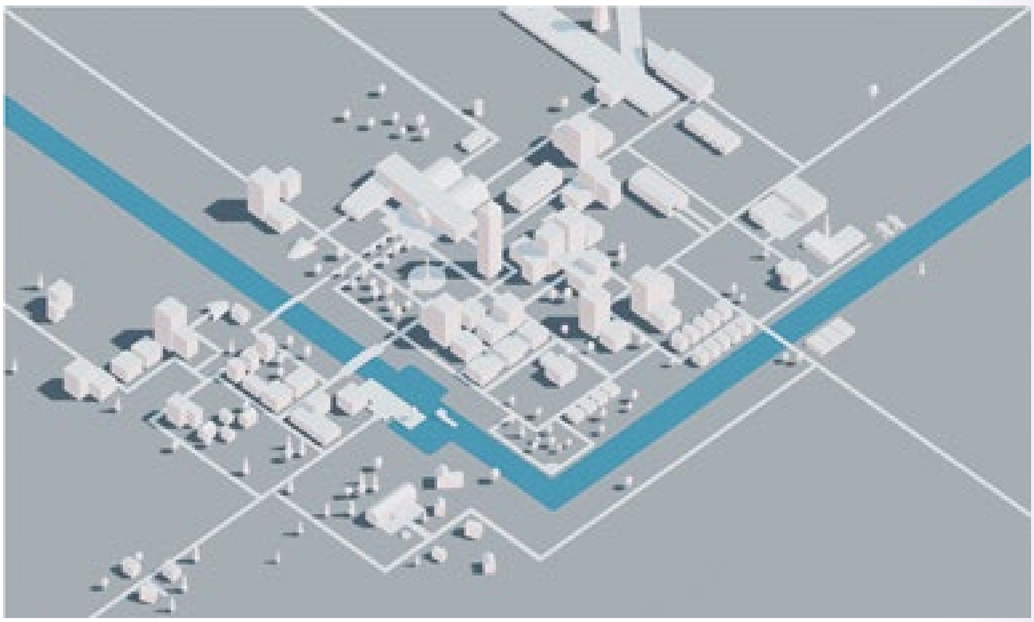


Fig. 4 Configuration of the »altitudes« (Source: Andrea Krajewski and Sabine Reitmaier)

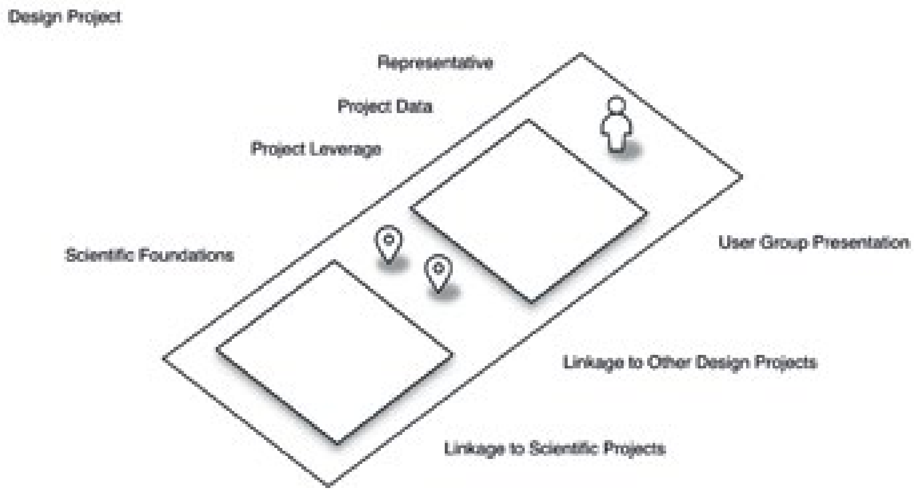


Fig. 5 The design project as a demonstration of user-oriented, systemic integration in a mobility network (Source: Andrea Krajewski and Sabine Reitmaier)

encourage emotional engagement and personal identification through design. For this purpose, design tools such as storytelling, user guidance, hierarchization of content, color palette, pictograms, fonts, and a layout that adapts to different screen sizes were applied. These are to be understood as a kind of grammar that enables consistent, easy-to-learn access for a broad group of users at different points of interaction with the guide (↳Fig. 6).[04]

The Mobility Design Guide's Future Image

One of the most significant findings from the interviews of those involved in the planning and implementation of mobility projects was that the knowledge of the Mobility Design Guide should be strategically anchored and capable of being deployed in the future. This highest »altitude« in the systemic view is referred to in the Mobility Design Guide as the »future image.« This is intended to capture and depict mobility modes that are preferable and desirable, but not to make predictions about how events will unfold. Future images in the Mobility Design Guide illustrate ways in which decision-makers in transportation policy, managing directors of transportation companies, urban and transportation planners, and project managers involved in implementation can approach the complex topic of future, networked, environmentally friendly mobility from the standpoint of mobility design and research.

The methodological approach used for developing the future structure of the Mobility Design Guide is called »backcasting« (Robinson 1982; Miola 2008: 14). Backcasting is understood as a normative, design-oriented method that formulates desirable future developments in a standardized manner, thus creating spaces in which measures and objectives can be determined as to how this desirable future can be achieved. In the design field, this is used among other methods, for example, in »transition design« (Candy 2019: 18). In terms of methodology, this was transferred to the planning, design, and implementation of projects in the mobility sector. Accordingly, the Mobility Design Guide shows thematically grouped perspectives for development that can be used to discuss key tasks. In addition, possible areas in which a systemically oriented, user-centered mobility design can be applied are clarified. Structured in this way, the content is intended to inspire people to work together with other stakeholders to conceive of networked and environmentally friendly mobility as a coherent whole, as a system, and to use the application structure thus developed to draw up new guiding principles for planning and design.

The Mobility Design Guide's vision of the future is based on central theses that were developed in a »ten-year horizon« workshop and then condensed into four key future mobility topics during subsequent workshops.[05] These describe the social,

Fig. 6 Design details: »Inter« Font, Color Palette, Icon Set (Source: Andrea Krajewski and Sabine Reitmaier)

economic, technological, and ecological dimensions of a more desirable, user-oriented vision of future mobility. The textual interpretation of their focal points is as follows:

- Future mobility is smart enough.
- Future mobility is needs-based.
- Future mobility is accessible to all.
- Future mobility is designed for the long term (↳Fig. 7).

The guide uses design projects as examples to show how ideas about future images can be explored through a step-by-step design process. However, these design projects do not only provide visual material and inspiration; they also provide a methodical framework for developing systemically conceived mobility solutions based on the key aspects of mobility (vision), the definition of project objectives (mission), and the associated actions (levers), which answer the needs of transportation users on rational, socioemotional, and symbolic-emotional levels. These design projects are linked to the findings of the research projects carried out as part of the »Infrastructure–Design–Society« research network—also documented in the Mobility Design Guide. The contents of the guide include concepts and design projects from the fields of design and architecture, scientific investigations of transportation planning and social science mobility research, and communication technology experiments, which also include research conducted on an interdisciplinary basis. In addition, there are existing precedents realized by external practitioners.

In this way, it was possible to meet the essential requirements for a Mobility Design Guide as they emerged from the interviews with potential future users:

- A consistent narrative and strict user guidance facilitate access to the complex topic of future mobility design.
- Different entry points are provided for various target groups and interests.
- Strategic and design approaches are methodically combined in one process.

04 The »Inter« font family has a high x-height to improve legibility of uppercase and lowercase letters. Also included in the package are open font features such as contextual alternates, tabular numerals, etc. As an open-source product, this font is under constant development.

05 The workshops were held as part of the design subproject within the research network »Infrastructure–Design–Society« (see note 1). Andrea Krajewski, Sabine Reitmaier, Anna-Lena Möckl, Julian Schwarze, Janina Albrecht, Peter Eckart, and Kai Vöckler participated.

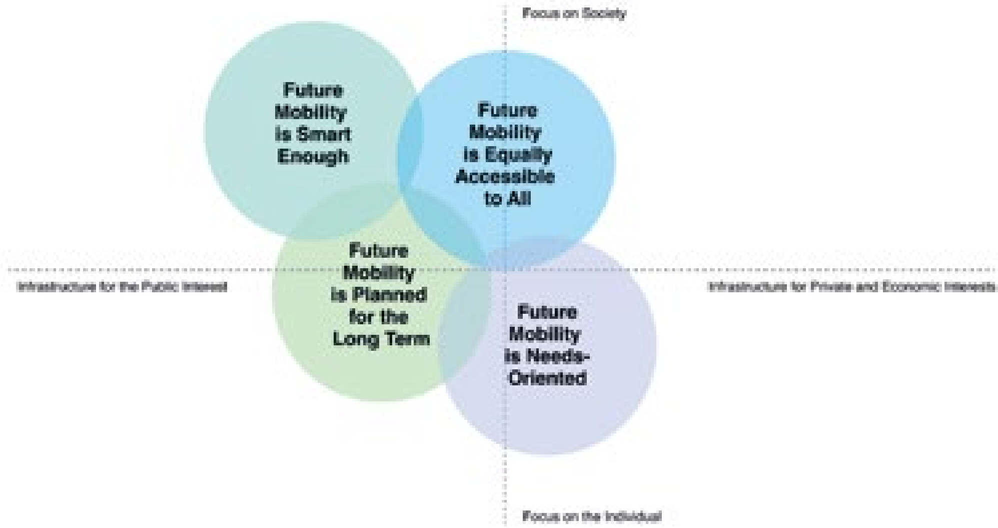


Fig. 7 Vision of the future with focal points (Source: Andrea Krajewski and Sabine Reitmaier)

- Low-threshold access and the networking of disciplinary perspectives enable interdisciplinary exchange.
- Furthermore, an expandable structure is flexible enough in itself to accommodate additional and new insights from mobility design.
- Last but not least, a strategically forward-looking guide anticipates future developments and thus also supports decision-making processes (↳Fig. 8).

Outlook and Further Development

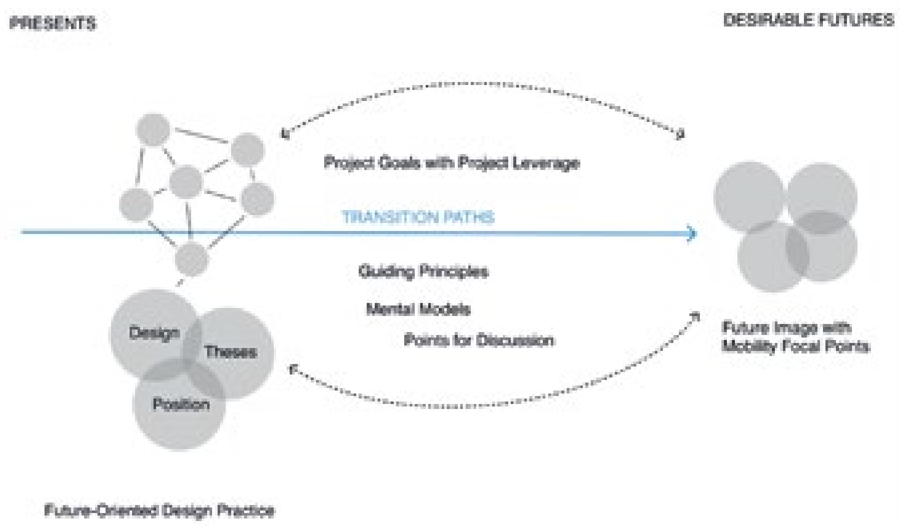
The Mobility Design Guide was implemented as a basic version for teaching mobility design. It introduces the methodological approach of desired mobility visions and human-centered design of mobility systems based on scientific research. A subsequent, future version of the Mobility Design Guide could build on this by incorporating more detailed methodological principles of mobility design and additional illustrative design projects.

Furthermore, usage options could be expanded according to the requirements of the target group. In this context, it was suggested that the contents of the guide could be exported and made accessible to regular users in their profiles. In this way, they could collect content and, for example, use it as a discussion aid in meetings. It would also be conceivable to use the guide as the basis for strategic cooperation among stakeholders in a mobility project, where guiding principles and design and scientific projects could be brought together in a joint process adapted to the respective urban region.

The Mobility Design Guide could also serve as a strategic platform for further interdisciplinary research and development in the field of mobility design. One research topic that has developed over the course of the project is an updating of the concept of mobility with regard to the increasing use of digital technologies in all areas of life, as well as their influence on user expectations and mental models. For all those involved in mobility design, this means turning to the planning, design, and organization of multioptional action scenarios in a technologically supported, complex overall system (see Krajewski and Reitmaier in this volume).

Finally, the Mobility Design Guide can be expanded into a digital, interactive real laboratory for the participatory development and design of visions of the future. In virtual workshops and digital discovery courses, desirable future scenarios can be created that could be experienced and evaluated with the help of designed digital artifacts. The objective of such experiences is, on the one hand, the development of alternative mental models among transportation stakeholders, political decision-makers, and urban and transportation planners.[06] This will help to facilitate the introduction of innovative sustainable mobility

Fig. 8 Diagram of the development of the future vision in the Mobility Design Guide inspired by Stuart Candy and Terry Irwin (Candy 2019: 19) (Source: Andrea Krajewski and Sabine Reitmaier).



concepts, since existing models will then no longer act as a kind of brake.[07] On the other hand, the future images thus developed can be investigated by means of common user-experience research practices with potential users. The Mobility Design Guide here serves as an interactive platform and a location for knowledge transfer between mobility design and research on mobility and the future.

06 The term mental model refers to conceptual ideas based on experience that are used to deal with an artifact or system and the resulting consequences and meanings (Dutke 1994; Krippendorff 2013). Addressing specific mental models in a targeted manner is particularly important in the design of innovative systems.

07 Of interest in this context is the research of Corina Angheliou, who specifically examines how methods of futurology and design can contribute to sustainable, innovative transformations (Angheliou et al. 2020).

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Connective Mobility

Changes in Mobility Behavior through Changes in the Socio-cultural and Physical Environment

A Psychological Perspective

Sonja Haustein

Although the need for more sustainable transport has been discussed for decades, our transport systems are still far from sustainable. Greenhouse gas emissions from transport increased by 20 percent in the EU between 1990 and 2018 (EEA 2020). City dwellers still suffer from local air and noise pollution and private cars occupy space that is missing for recreation, walking, and cycling (Creutzig et al. 2020). Residents of rural areas often depend on a car to fulfil their mobility needs, leaving carless people behind (Ahern and Hine 2012; Mattioli 2014). Road traffic dominated by motorized transport additionally poses a safety threat, with road injuries being a leading cause of death globally (Chen et al. 2019).

More sustainable transport requires a change in mobility behavior as technological advancements alone are not sufficient (Schwanen et al. 2011; Skippon et al. 2012) and may lead to rebound effects (Millonig and Haustein 2020). To identify effective behavior change measures, it is relevant to understand under what circumstances people change their mobility behavior and what mental mechanisms are involved in these behavior change processes. This chapter provides an overview on most relevant psychological theories of behavior change in transport and how change mechanisms are linked to the sociocultural and physical environment. It raises questions of cause and effect and how they can be addressed in future studies combining advanced technologies of data collection and analysis with qualitative methods, utilizing the advances of interdisciplinary research.

Understanding the Process of Behavior Change

During recent decades, our understanding of mobility behavior and the various related factors has increased substantially. However, the question of which environmental factors and societal processes lead to a change in mobility behavior has still only been answered rudimentarily (Haustein 2021a). The mobility biographies approach (Lanzendorf 2003) offers a useful framework to explain changes in mobility behavior. Key events in the course of a life are considered to be the main drivers of behavior change. These events can interrupt people's established travel habits, which are reconsidered and eventually changed. Müggenburg et al. (2015) distinguish between three types of key events that determine everyday mobility decisions: life events (e.g., childbirth, retirement), adaptations in long-term mobility decisions (e.g., residential relocation, car purchase/disposal), and exogenous interventions (e.g., new infrastructure, changes in urban design). According to the mobility biographies approach, these key events influence each other and are influenced by long-term processes (that is ageing and socialization, period and cohort effects). Long-term and everyday mobility decisions are assumed to mutually affect each other. Based on retrospective interviews, Janke and Handy (2019) explored how life events changed cycling attitudes and behavior and pointed to a bidirectional relationship between both variables. Initiating a deliberation process was identified as one of several ways through which life events trigger behavior change.

Deliberate processes of behavior change are described in stage models of behavior change, perhaps in most detail in the stage model of self-regulated behavioral change (SSBC; Bamberg 2013a, 2013b). The model specifies which psychological factors and processes trigger stage progression, starting with an unspecific goal to change behavior over more specific steps and actions, which can finally lead to the establishment of a new behavior, which may then form a new habit. SSBC integrates assumptions of static action models, in particular the theory of planned behavior (TPB; Ajzen 1991) and the norm-activation model (NAM; Schwartz 1977; Schwartz and Howard 1981) and previous stage models.

TPB is probably the most frequently applied theoretical framework when explaining transport behavior. According to TPB, intention is the main predictor of behavior. Intention is influenced by attitude toward the behavior, which is the evaluation of the positive and negative consequences of the behavior, and the subjective norm, which is the perception of social approval of the behavior. Subjective norm has later been supplemented by descriptive norm—the behavior that is observed in others and found to be a relevant addition to explain transport behavior (Eriksson and Forward 2011; Møller and Haustein 2014).

A third predictor of both intention and behavior is perceived behavioral control (PBC), which describes how easy or difficult a person perceives the conduction of a target behavior (such as cycling to work). While it may be completely determined by actual behavioral control, PBC typically differs from actual behavioral control because different people perceive the same situations or environments as more or less supportive for a behavior (such as cycling). In the context of mode choice, PBC mostly relates to the perception of the transport infrastructure. To explicitly account for perceived requirements and constraints resulting from the personal living situation, TPB was extended by the construct of perceived mobility necessities (PMN), capturing demands from family and work that require a high level of mobility, hampering car use reduction (Haustein and Hunecke 2007). A recent study in Copenhagen indicates that the effect of PMN on cycling is context-specific: in a supportive cycling environment, PMN do not only encourage car use but also cycling (Thorhauge et al. 2020). PMN have also been identified as a relevant determinant of car sharing adoption (Jain et al. 2021) and are related to an increase in car ownership over time (Jain et al. 2020; Haustein 2021b).

While the standard attitude measure in TPB is often reduced to the positive versus negative evaluation of the behavior or to functional and instrumental aspects of the behavior, such as convenience, saved travel time and money, attitude has been exchanged or complemented by symbolic and affective motives (Hunecke et al. 2007).

In case of mode choice, this includes to what extent the use of a specific transport mode is related to fun and passion (enjoyment), status and prestige, or freedom and autonomy (Haustein et al. 2009; Steg 2005; Zhao and Zhao 2020). Indeed, it has been demonstrated that more than half of the value of car-ownership comprises non-use value (Moody et al. 2021).

While TPB assumes that people aim to maximize their own benefits, the norm-activation model focuses on the moral obligation to engage in a behavior (Schwartz and Howard 1981). The model views proenvironmental behavior as the consequence of the activation of personal norm—the perceived obligation to act according to own moral values. Many proenvironmental actions are associated with behavioral costs, which may prohibit the activation of personal norm. Indeed, several conditions need to be fulfilled before it is activated. First, people must be aware that a given behavior (e.g., car use) has negative consequences for the environment (awareness of need). Second, people need to be aware that their own behavior contributes to the problem and thus feel responsible for the consequences of their behavior (ascription of responsibility). Third, people need to believe that their behavior will help solving the problem (outcome efficacy). Here it is important that people expect others to act in an environmentally friendly way as well; otherwise, others' behaviors can be used to justify one's own unsustainable behavior, similar to the denial of consequences and the denial of responsibility. Finally, people must perceive the ability to act according to their personal norm (e.g., they must be able to avoid car trips).

While the norm-activation model focuses on acting in accordance with one's own moral standards and the TPB focuses on optimizing one's own benefits, Lindenberg and Steg (2007) integrated both approaches in the goal-framing theory. Apart from the normative goal (e.g., protecting the environment) and the gain goal (e.g., saving time and money), the goal-framing theory additionally considers hedonic goals (e.g., enjoying the trip) to determine a behavioral choice. All three goals are assumed to frame the way people process information and how they act in a given situation. What goals are predominant depends both on people's underlying values and situational factors and may thus vary for the same person in different contexts.

More specific action models that combine assumptions of the TPB and the norm-activation model have been suggested by Klöckner and Blöbaum (2010) and Zavareh et al. (2020), adding habits and self-identity, respectively.

Sociocultural and Spatial Context: Mobility Cultures

Besides the natural and built environment (Christiansen et al. 2016; Hillnhütter 2021; Nielsen et al. 2018; Susilo and Maat 2007), a supportive environment for the use of alternative transport modes also includes nonmaterial aspects. How the use of specific transport modes is perceived in a city or in a broader cultural context, and what symbolic meanings are connected with its use, has been found to play a relevant role for mode choice (Ashmore et al. 2020; Sovacool and Axsen 2018). Objective and subjective elements as well as the interaction of actors, stakeholders, and infrastructures are considered jointly when describing the mobility culture of a city or region (Deffner et al. 2006; Haustein, Koglin et al. 2020). A city may be described as a »transit metropolis« (Klinger et al. 2013), while several cycling (sub)cultures can be differentiated within the same city (Hoor 2020a). This also illustrates how differently the concept of mobility culture is understood, operationalized, and examined. On the one hand, it is argued that only a joint consideration of all elements of mobility cultures based on qualitative methods is adequate and meaningful since a quantitative assessment and comparison of mobility cultures may neglect the negotiation processes through which mobility cultures are in the first place created, consolidated, and changed (Hoor 2020b). On the other hand, it is argued that a definition that includes nearly all aspects of urban mobility may become a »superficial fashion term« and along this line of argumentation an empirical operationalization of mobility culture as injunctive normative beliefs is suggested (Bamberg et al. 2020). Similarly, Basaran et al. (2021) suggested a cycling norm index that measures how cycling is perceived in a region as a proxy for the predominant cycling culture. An alternative way of measuring mobility culture could be an application of a stated preference approach as used in Moody et al. (2021), where a low value of car ownership, in particular a low non-use value, would indicate a more sustainable mobility culture that has decoupled car ownership from well-being and social inclusion (Haustein 2021c).

Another way of studying the effect of different mobility cultures is to examine people's travel behavior adaption when moving to a different city. Examining people who recently moved, Klinger and Lanzendorf (2016) found that cycling—as compared to other modes—is more affected by citywide sociocultural attributes, such as the perceived acceptance of cyclists, than by specific local/neighborhood characteristics. However, the specific process of how and under which circumstances the experience of a new mobility culture changes attitudes, norms, and travel behavior is far from being understood and needs further investigation.

Causality in Behavior Change

Causality patterns in long-term mobility decisions are complex and do not necessarily follow a simple cause-and-effect logic. Challenges arise particularly from endogeneity, which occurs when a relevant variable is omitted in a causal model or when the dependent variable is (also) a predictor or the independent variable, in case of multidirectional causality (Avramovska 2020). The latter has for example been examined in the context of residential self-selection (Kroesen 2019). Residential relocation is among the most examined long-term mobility decisions. Moving to suburban locations is typically followed by an increase in car use, while the opposite is the case for moving into the city (Scheiner and Holz-Rau 2013). Research around residential self-selection indicates that residential choice is influenced by travel attitudes, which need to be accounted for to avoid an overestimation of environmental effects on mode choice (Cao et al. 2009). However, increasing evidence is found for the »reversed causal relation,« meaning that the new location changes travel attitudes (De Vos et al. 2018; van de Coevering et al. 2021). Additionally, multidirectional causality is at play in the relationship between car use and car attitudes (Moody and Zhao 2020), meaning that car use is not only influenced by attitudes but also that there is a strong path back, which also applies for other travel modes (Kroesen et al. 2017). Although the reciprocal relationship between attitude and behavior in mode choice was demonstrated four decades ago (Dobson et al. 1978), it has rarely been considered in the empirical application of psychological models, especially not in the frequently applied TPB, with few exceptions (Thøgersen 2006).

Yet, TPB also assumes that feedback from one's own behavior is likely to affect one's own beliefs and thereby also future intentions and actions (Fishbein and Ajzen 2010). Recently, empirical evidence that intention affects subjective norms and attitudes in a reverse-causal direction has also been provided (Sussman and Gifford 2019), demonstrating a need to consider the reciprocal relationships between all TPB-components, not only the attitude-behavior relationship, in future research.

Several transport studies (De Vos and Singleton 2020) use Festinger's theory of cognitive dissonance (1957) to explain the alignment of attitudes and behavior over time. According to Festinger, incongruence in attitude and behavior leads to mental discomfort, which causes an adaption of behavior and/or attitudes. Similarly, the norm-activation model suggests that not acting according to personal or social norms leads to unpleasant feelings of guilt or shame, respectively. To avoid this mental discomfort, people practice different strategies, such as denying the need for action or their own responsibility (Møller et al. 2018; Kroesen 2013; Lamb et al. 2020). While there is empirical evidence for the relationship between the involved sociopsychological factors, the involved mental processes, and, in particular, the context in which a given attitude or norm does or does not lead to action, has rarely been examined in longitudinal studies, and thus the basis for causal conclusions is generally limited.

Context-conditionality is indeed another causality challenge. There are several examples of transport choices where a cause-effect relationship depends on the sociocultural and/or spatial context. Immigrant background, for example, increases the likelihood of cycling in low-cycling countries (Smart 2010) but decreases it in high-cycling countries (Haustein, Kroesen et al. 2020). Similarly, age and gender play a role for the uptake of cycling in low- but not in high-cycling countries, suggesting that the provision of safe infrastructure and travel socialization plays a relevant role (Aldred et al. 2016; Haustein, Koglin et al. 2020).

Future Perspectives

Advancements in data collection and analysis can be named as factors that are expected to expand our understanding of behavior and behavior change in transport. Biosensor data can more and more easily be collected with wearable sensors, such as advanced wristbands (Jimenez-Molina et al. 2018). The incorporation of psychophysiological data measured while traveling has the potential to improve survey-based modeling of transport choices (Castro et al. 2020). Besides showing individual differences in the perception of travel options, it may especially help to identify critical aspects in the journey leading to stress and mental discomfort or environmental aspects leading to enjoyment and relaxation and thereby provide concrete hints for improvements in design, particularly when combined with surveys, qualitative interviews, or focus groups.

A better understanding of the long-term processes of behavior change and connecting it to changes in the environment and personal living circumstances requires more and better (quantitative and qualitative) longitudinal data and adequate methods to identify causal relationships in such large, complex datasets. The detection and inference of causality is a relatively new and growing research area in machine learning (Peters et al. 2017), which offers great potential for the verification of theoretical assumptions and the detection of causal relationships in the context of transport behavior and may lead to great theoretical and methodological advancements in transport research.

While this chapter has emphasized the psychological perspective to behavior change, it also highlights that understanding behavior change in transport profits from an interdisciplinary approach, combining expertise in advanced modeling, psychology, physiology, sociology, urban design, transport planning and geography.

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Mobility as a Key to the Livable City

Annette Rudolph-Cleff
and Björn Hekmati

As a result of the mobility revolution, urban spaces and transportation infrastructure need to be adapted in the coming decades. Changes in drive-train technology, vehicles, transport modes, user behavior, and road traffic regulations have consequences for urban environments. These necessary conversions will be costly and fundamentally alter the character of cities in the long term. It is not yet entirely clear which transportation modes and types of mobility will predominate in the future, but it is highly likely that our cities will become more differentiated and more distinct from one another in this respect than they are today (Klinger et al. 2013). Factors from very different fields will influence the development of our cities in the process. The question of affordable housing, the transformation of inner cities, and strategies for adapting to changing climatic conditions are all important factors driving the discourse on livable cities. The European mission statement of the New Leipzig Charter (BMI 2020), based on the three pillars of sustainability, strongly emphasizes the topics of a city oriented toward the common good, a green city, and a productive city as target parameters. Mobility design is a central theme in this context. However, sociopolitical considerations will determine the concrete factors that will shape urban planning measures and affect the role that environmentally friendly mobility will assume in the competing demands for space.

Dystopias associated with the climate crisis, such as traffic collapse and inhospitable urban wastelands, are of little help in the search for new solutions. But what are the desired models and visions of a livable city that has safe, inclusive, and sustainable spaces? Images that anticipate desired scenarios (Rittel 2013: 123ff.), as well as high-quality design projects already implemented that serve as model solutions, can inspire and provide a basis for discussion, thus shaping the future course of urban redevelopment. However, determining which solutions can be successfully implemented in which places depends on a multitude of reciprocal influences. In this respect, the question of »What to do?« initially takes a back seat to the question of »How to proceed?« Which methods and processes must be established in order to transform the car-friendly city into a livable one? Who are the key players and how do they work together? What are the first steps toward mobility concepts for the livable city?

The Example of Copenhagen

In the discussion below, we will consider the transformation of urban spaces in the city of Copenhagen, which as the »Green Capital of Europe« stands for ambitious sustainability goals and high-quality living standards (Bolik 2019: 139). The methodology used here is based on literature and media analyses, site visits, and photographic documentation, as well as interviews with experts involved in the transformation process in different capacities; these interviews were conducted in May 2019.

At a very early stage, Copenhagen set itself the goal of becoming the world's first climate-neutral city by 2025 (Climate Plan 2009; Copenhagen City 2009: 3) and is considered a pioneer in innovative projects, most of which have been implemented within the existing urban fabric. Environmentally friendly mobility is a focal point (Copenhagen City 2009: 5). Cycling conditions have already been improved across the city through a convenient, continuous network of paths. Copenhagen is therefore often cited as a model for the bicycle-friendly city (Kords 2020). Although numerous Dutch cities are just as far along as Copenhagen in terms of bicycle use in relation to the modal split and associated infrastructure (Copenhagenize Index 2019; Statista 2021; BMVI 2021), the origins and the leading figures behind the Danish capital's development into a bicycle metropolis are unique.

At the beginning of the 1970s, Copenhagen was as much of a car-oriented city as most other European cities. Public spaces were occupied by parked cars, the streets were reserved for motorized individual transport, and a large highway through the city center was planned from 1958 as part of the »City Plan Vest,« which was not implemented. In 1972, even the streetcar network was abolished. Then came the oil crises and with these, by necessity, a new way of thinking. The transformation of the city into a bicycle metropolis, however, did not pick up speed until the 1980s. Today's situation is arguably the result of various factors that ensured success, as outlined below.

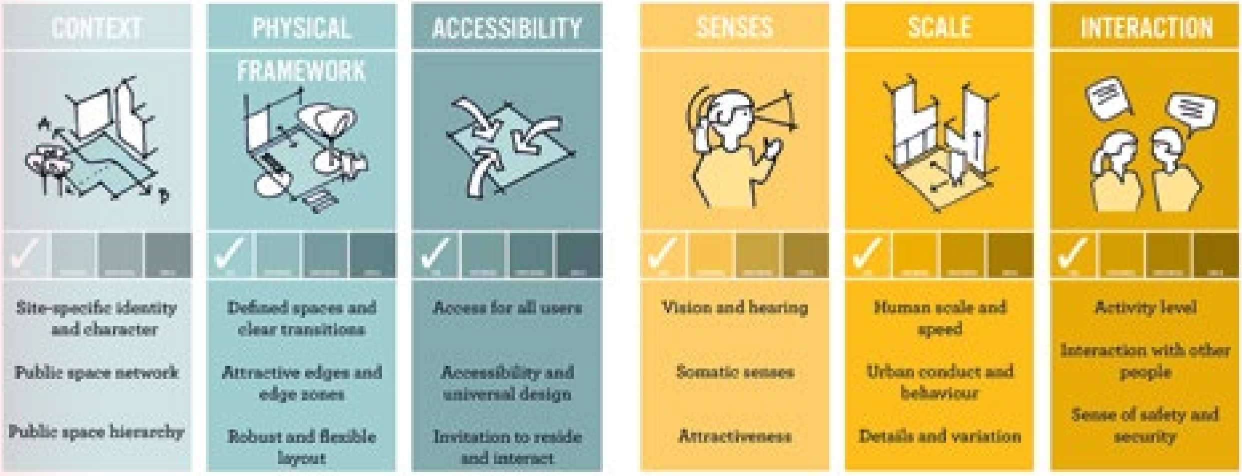

Fig. 1 Planning toolboxes: implementation of sustainability targets for Copenhagen (Source: Schulze + Grassov, Copenhagen)

Back in the early 1980s, the city already had a progressive head of the municipal transportation department in the person of Jens Kramer Mikkelsen. He was subsequently elected mayor of the city in 1989 and remained in office until 2004. The city's vision of making Copenhagen more family-friendly and strengthening public transport was reflected in the construction of the new subway. This focus was continued under the former minister and European Commissioner Ritt Bjerregaard, who was elected mayor in 2006 (Bondam 2018). Together with her director of technology and environment, Klaus Bondam, she implemented plans to make Copenhagen the most bicycle-friendly city in the world. In order to gain acceptance among city policymakers as well as the citizenry for this project, which aimed to significantly reduce air and noise pollution, two documents were given a central role: »The Environmental Metropolis« and »The Metropolis for People.« Both publications were strongly influenced by the thinking of the Copenhagen architect and urban planner Jan Gehl (Bondam 2018:154).

According to the urban planner Oliver Schulze, who supported the City of Copenhagen in embedding sustainability goals within municipal urban land use plans, the continuity of personnel and expertise in transportation planning at the highest level was certainly beneficial for the long-term objective of realizing bicycle-friendly urban redevelopment (Schulze 2019). The political-administrative sphere was enriched by inputs from academia, primarily Jan Gehl, who made a substantial contribution through his empirical research and design proposals (Gehl 2010, 2012). His central tenet that urban space should be experienced at the speed of pedestrians as a »city at eye level« has informed urban redevelopment as a guiding design principle; this included many practical planning cues calling for a human scale for streets, squares, and neighborhoods. The resulting redevelopment strategy focuses neither on neighborhoods nor on traffic types, but rather takes a holistic view of the city as a totality. Open space design, parking management, and expansion of bicycle infrastructure, for example, were synchronized across the entire urban area in Copenhagen. This was done in such a way that there was never a parking shortage, and every parking space eliminated made an immediate contribution to the realization of high-quality bicycle infrastructure design (Schulze 2019; ↳Fig. 1).

As far as possible, the planning culture was designed to be fault-tolerant. Not every intervention endured; there were missteps and misplanning, learning processes and corrections. This fault-tolerance not only helped to optimize the infrastructure, but also gave the urban community a knowledge edge (Schulze 2019). This is reflected,

Fig. 2 Cykelslangen
(Source: Björn Hekmati)

among other things, in the global consulting activities of the Copenhagenize Design Company and the media presence of its founder and CEO Mikael Colville-Andersen, as well as in Jan Gehl's international visibility.

The City of Copenhagen closely monitors and documents traffic conditions; since 1996, bicycle-specific data has been collected and published in the biennial »Bicycle Account« (Cycling Embassy of Denmark 2020). On the one hand, these and other statistical sources help the city to make the right decisions and to identify and correct undesirable consequences at an early stage. On the other, a good data base helps objectify public debate and even generates acceptance for supposedly unpopular measures (State of Green 2020).

But in addition to the protagonists and processes involved in redevelopment, another factor has played an essential role: good design that can be experienced in everyday life. The built transportation infrastructure in Copenhagen is functional, a pleasure to use, and of high design quality. The inhabitants identify with it, are proud of it, and have developed their own specific mobility culture (Schulze 2019). Function, performance, and appearance are not mutually exclusive, because good design does not favor one of these aspects over the others.

One example of this kind of design is the Lille Langebro bicycle bridge by Dissing+Weitling Architekten (2014), also known colloquially as Cykelslangen (↳Fig. 2). This steel bridge, measuring 190 meters in length and only 4 meters in width, has lighting integrated into the railing and an orange road surface. It bridges a secondary harbor basin adjacent to the Fisketorvet shopping center and connects to another bicycle bridge that crosses over the water to the Vesterbro district. It has an S-shaped curve; this extension of the path, which might seem unnecessary, allowed for a slight gradient reduction. It is great fun to roll down this snake; the challenge posed by the curve requires some concentration and thus may also enhance safety for oncoming traffic on this narrow structure. In addition, the shape of the bridge serves another function that is not apparent from the cyclist's perspective: it increases the amenity quality of the bankside along the basin through its shape and the materiality of its underside. A dead-straight structure at this point would certainly have come under the final construction costs of around 5.1 million euros (Dissing+Weitling 2021); however, this presumably would only have fulfilled the function of closing the gap, without contributing to the other aspects noted above. Notably, the design of this piece of technical infrastructure was the result of a competition (Eckart and Vöckler 2022: 206), where the quality of different solutions for this planning problem was discussed via the visual design presentation. These not only illustrated the requirements of the competition program, but also represented the urban development vision. The process of selecting the best solution is both an appropriate means of ensuring quality planning and of promoting architectural culture. The high number of awards won by this project

Fig. 3 M1 metro station
(Source: Björn Hekmati)

over a five-year period (2013–2018) speaks for itself (Dissing+Weitling 2021). With Cykelslangen, an integrated solution was realized that enriches the urban space in multiple ways.

Equally noteworthy is the approach taken by the city's driverless metro network (operations began in 2002) (↳Fig. 3+4). The stations were designed to function smoothly and to have as timeless an appearance as possible (Colville-Andersen 2018). As a result, their designs are very similar to one another. Advertising or even commercial uses within the stations were avoided entirely. Underground stations are lit with daylight down to the platform (as far as technically feasible). The Copenhagen Metro can be used very efficiently, since there are no orientation problems in the stations, the digital ticketing system works in a straightforward way, and the very high frequency facilitates rapid travel without a fixed timetable (Copenhagen Metro 2017). It is fascinating to sit at the very front of the driverless trains and look in the direction of travel into the tunnels or down onto the tracks. The functional minimalism of the high-quality station architecture and furnishings, which scarcely allows individual stations to be distinguished, represents a radical statement for public transport

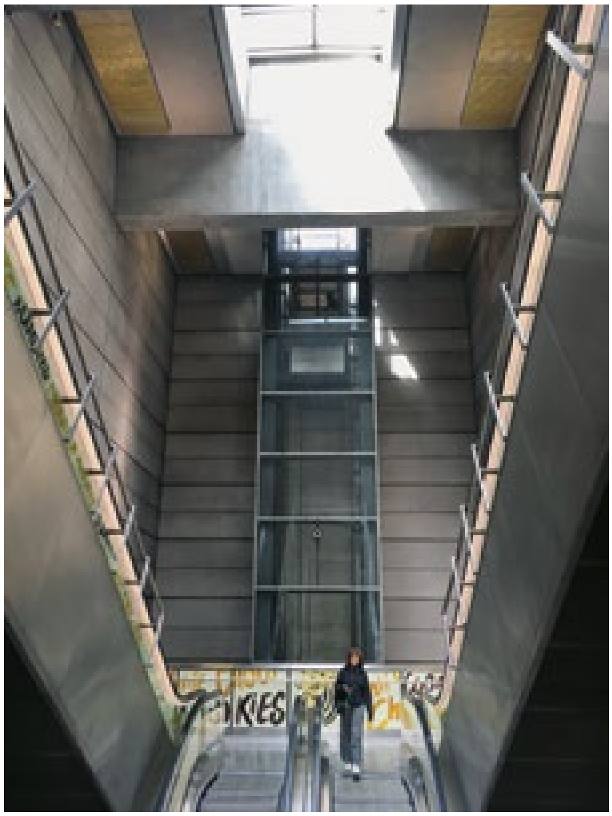

Fig. 4 M1 metro station
(Source: Björn Hekmati)

Fig. 5 Ørestad: transit-oriented development, metro M1 (Source: Björn Hekmati)

and »A-to-B-ism« (Colville-Andersen 2018). Users have in fact criticized the rigorous design concept of Line M1, which subsequently led to differentiations being made within the system as part of a comprehensive color scheme for Lines M2, M3, and M4, in keeping with the minimalist concept. This strategy does not focus on the individuality or recognizability of stations in the urban context, but rather interprets the station as part of the rail network and the transport system, making it recognizable as a coherent infrastructure system.

The M1 line of this system also connects the district of Ørestad south of the city center. This area, which has been in planning and construction stages since 1992, extends as a fixed rectangle measuring roughly 600 meters wide and 5 kilometers long along the straight elevated railway tracks and an accompanying road flanked on both sides by wide bicycle highways (↳Fig. 5). A first for Denmark, the M1 line was the initial construction project within the the urban development plan for this district. Workers on the major construction

Fig. 6 Ørestad: built transition in the landscape (Source: Björn Hekmati)

sites that followed were soon able to travel to work via public transport. Ørestad is a radical strip city design for about 20,000 inhabitants whose scale was oriented to transportation infrastructure capacities. Accordingly, on its southern edge, Ørestad borders directly on the Pinseskoven nature reserve, where there is a metro terminus and buildings of up to eight stories forming a dense urban fabric. In this way it makes a clear statement against urban sprawl (Jordan 2002: 398; ↳Fig. 6).

Several buildings in the district were designed by renowned national and international architects, including Bjarke Ingels, or BIG, (8 Tallet, MTN the Mountain, VM Houses), Jean Nouvel (DR Koncerthuset), Adept (Cubic Houses), and Cobe (Karen Blixens Plads). The design program, which includes master plans from 2014 and 2017 (by Daniel Libeskind and Cobe, among others), infrastructure planning, and multistage competitions for major buildings as well as square and landscape designs (see competitionline), ranges from integrated access and mobility concepts to details such as bicycle parking facilities. Bjarke Ingels's (or BIG's) residential project MTN the Mountain, a kind of terraced housing complex built on top of a parking garage, makes a statement about the use of motorized individual vehicles by means of a wall relief: a bellowing stag stands atop a stack of high-performance cars, ironically holding up a mirror to parking garage users (↳Fig. 7). Ørestad is not yet finished nor fully occupied, so it remains to be seen whether this planning approach may be considered sustainable. As a model for courageous planning and consistent integration, however, the Ørestad district already serves as an exemplar.

In respect to climate change adaptation, the City of Copenhagen has taken a bold step forward. After the heavy rainfall of July 2011, the City of

Copenhagen decided to implement an initial demonstration project for city-wide climate adaptation based on the Climate Adaptation Plan (City of Copenhagen 2011) and the strategic Cloudburst Management Plan (City of Copenhagen 2012). The landscape architecture firm Tredje Natur of Copenhagen won the Europan 11 competition with its vision for a diverse neighborhood in the Sankt Kjelds quarter. They were commissioned to translate the competition entry into a comprehensive vision for Denmark's first climate-friendly neighborhood (Rafn 2015). This resulted in a workable concept that could serve as a guide for further development of the neighborhood. In parallel, the Sankt-Kjelds quarter was approved as a neighborhood renewal project (2012–2016). This facilitated development synergies and allowed for a generous project budget consisting of financial support for urban renewal, climate adaptation, and wastewater management. According to the planner and project manager in charge at the City of Copenhagen, René Sommer Lindsay, in 2014 Tåsinge Square was realized as the first high-visibility pilot project, thanks to significant political pressure and a willingness to clarify legal obstacles in the development process (such as the water company's investment in public space, street surface drainage, and the fee schedule—see Lindsay 2017; Copenhagen City 2016: 10). The example of this plaza makes it clear that it is not primarily a matter of universal applicability, but of setting an example at the citywide level (Lindsay 2017). At the same time, a competition was held for Saint Kjelds Square and Bryggervangen Street, which was won by the landscape architecture firm SLA in cooperation with ALECTIA (City of Copenhagen 2015: 15). Their design greatly reduces the size of the existing traffic circle and edges it with four large green zones (↳Figs. 8+9).

Fig. 7 Ørestad: wall relief in the parking garage of the MTN housing project, BIG. (Source: Björn Hekmati)

This has resulted in a model neighborhood for a climate-resilient residential quarter in Østerbro, which will be used to develop methods and expertise to advance climate protection and flood prevention in Copenhagen over the next twenty years. The first climate-change-resilient neighborhood is set to become Copenhagen's greenest city center neighborhood—which can also withstand intense rainfall. Green streets, blooming courtyards, diverse fauna, and landscaped drainage areas and ditches will provide the new building blocks for the neighborhood. The City of Copenhagen is working closely with the Copenhagen utility HOFOR, as well as the Østerbro Environmental Center and neighborhood residents, who are leading their own initiatives through community gardens and urban farming (e.g., the ØsterGro rooftop farm, the Pavement Garden on Bryggervangen Street, and the Green Entrance). According to political scientist Torkil Lauesen, who is responsible for community involvement within the municipality, special attention has been paid to participation from the beginning since much of the land is privately owned. Information workshops and events were held in public spaces as a means of reaching as many residents as possible (Lauesen 2015). A specially established and funded committee not only assisted in planning

Fig. 8 Sankt Kjelds Quarter: Tåsinge Square (Source: Third Nature's Climate District design, https://www.tredjenatur.dk/en/portfolio/the-first-climate-district/)

Fig. 9 Sankt Kjelds Quarter (Source: Third Nature's Climate District design, https://www.tredjenatur.dk/en/portfolio/the-first-climate-district/)

and realization, but also initiated social campaigns following completion. Financial support was also granted to civic engagement for the realization of neighborhood gardens in public spaces (City of Copenhagen 2015: 23, 30, City of Copenhagen 2014b: 8). The initial design by landscape architects Tredje Natur was modified during the process in response to user perspectives; this diminished its striking design concept as a flowing space with soft forms (Bolik 2019: 197). However, according to the principle »the community is the expert« (PPS 2000, 2017), the desires and ideas of users are given a high level of priority in Copenhagen to ensure that the everyday spaces created are widely accepted (↳Fig. 10).

In the Sankt Kjelds neighborhood, scalable climate adaptation solutions have been created for the urban spaces of the future, right down to the careful detailing of the Copenhagen-style water-permeable paving and retention filters. Areas for water-sensitive urban design and biodiversity enhancement naturally come at the expense of transportation space. The previously oversized streets (City of Copenhagen 2015: 9) have been reduced to one lane, which is now shared by cyclists and motorized

Fig. 10 Bryggervangen (Source: Third Nature's Climate District design, https://www.tredjenatur.dk/en/portfolio/the-first-climate-district/)

traffic at reduced speeds. The few remaining parking spaces are unpaved. Of course, this is only possible by reducing traffic space as well as through radical traffic calming. With the climate-friendly city in mind, clear priorities were set for the blue-green infrastructure. The process of removing paving to unseal the soil was underpinned by citizen engagement and active communication; this was realized in a playful way using umbrellas that collect rainwater as well as creating a water playground where water can be pumped by hopping. The bicycle city of Copenhagen is facing up to the requirements of the climate-friendly city concept and is once again reorienting itself. Its plan to become the best bicycle city in the world was extended in 2009 by a City Council resolution; now Copenhagen wants to become the best city for people (Gehl 2017: 174). The »Climate Quarter« in Copenhagen is a radical statement along these lines, which has deliberately been allowed time to prove itself (↳Fig. 11).

Learning from Copenhagen

The example of Copenhagen along with the complexity of the planning processes and projects provides an answer to the question of strategies for transforming the car-oriented city into a livable one. Whether it is a bicycle bridge, a metro station, a planned city, or a »climate quarter«—Copenhagen's transformation into a livable city is being conceived and implemented holistically at all scales. Sustainable forms of mobility are not just enabled and encouraged: they are positively imprinted in cultural consciousness via architecture as a »heavy social medium« (Delitz 2009). Through the involvement of its inhabitants, urban space is transformed and enhanced, upgraded, or reinterpreted. Solutions are not conceived in purely technical terms nor optimized for only one aspect, but rather are realized to a high design standard in respect to the urban context.

Copenhagen's transformation shows that this requires a long period of time and multilayered processes involving multiple phases and diverse scales. These are long-term developments, combined with extensive investments and clear political objectives. They have not triggered a sudden turnaround, but rather a decades-long transformation and with it, sustainable changes in urban spaces and transport modes.

The case of Copenhagen clearly demonstrates the importance of committed actors who play a critical role in the development of objectives for the entire city and for dealing with land usages. These actors have a strategic vision of the scope for future action that must be safeguarded and executed. They are also able to initiate processes and move projects forward with determination. This is where the importance of the interface between science and politics becomes clear, as the collaboration with Jan Gehl attests. His image of the »city

Fig. 11 Climate adaptive design (Source: Climate Tile by Third Nature, https://www.tredjenatur.dk/en/portfolio/climatetile/)

at eye level« has informed urban decisions in Copenhagen and many other cities.

The first steps in implementation differ greatly but are always based on holistic planning approaches, an integrated administrative approach, and a deep understanding of the unique characteristics of the city and its inhabitants. From temporary individual measures intended to have a stabilizing effect, to hierarchical master planning and model projects, these activities all involved actors at various political levels (Wulfhorst et al. 2013: 257). Copenhagen's experience clearly shows that the recipe for success is not the mere accumulation of isolated measures; rather, what is needed are integrated concepts that define quality standards for the entire city and generate solutions geared to the location and users (Hoor 2020). The multistage competition and planning procedures that start with a concept competition, such as Europan, and end with a design competition, open up opportunities for testing the efficacy of proposed solutions through visual aids. Qualities cannot be conveyed abstractly, but only through the depiction of the actual project. It is therefore less individual solutions and more the special planning culture that distinguishes Copenhagen.

When looking at other cities and municipalities whose transportation and mobility design are considered exemplary, such as Barcelona, Amsterdam, Paris, or Karlsruhe, it becomes evident that design solutions offering high urban spatial quality respond in specific ways to urban contexts and their residents (Hofmann 2019; Eckart and Vöckler 2022). This contextual integration is a key to successful urban planning concepts, both in terms of urban design and in the organization of the planning and implementation processes.

Clearly, even highly differentiated transportation planning models that address the various modes of mobility have their limits when it comes to meeting the demands of a climate-friendly city. Driving on paved surfaces stands in the way of the necessary unsealing of the soil, which is where the competition for space in the European city becomes particularly obvious. The search for new concepts, however, also leads to great opportunities for urban development, as evident in model projects. For example, the reassessment of climate adaptation requirements and green space provision was initially the starting point for the Superilles (superblocks) in Barcelona (Eckart and Vöckler 2022: 156). Today, these superblocks are also celebrated as a sustainable transportation concept offering a new kind of urban environment, because they foster greater acceptance of a reduction in motorized individual vehicle usage (Ajuntament de Barcelona 2020).

The exciting developments in Barcelona, Amsterdam, Paris, and Karlsruhe are specifically designed for these cities and their inhabitants. The objectives and concepts of these individual initiatives aimed at promoting environmentally friendly mobility differ just as much from each other as do the procedural steps involved in their implementation. What these best-practice examples have in common is that they generate added value in terms of urban spatial quality that goes far beyond the issues of modal split or traffic flow optimization. Successful urban planning concepts are measured by their demonstrable contribution to the reduction of motorized individual vehicles, the high share of pedestrian and bicycle traffic, the contribution to climate protection and climate adaptation, and, last but not least, the living and amenity qualities in inclusive urban spaces. The interplay between science and politics determines their respective quality, as can be seen in the example of Copenhagen and more recently in that of Paris. The vision of the fifteen-minute city became the guiding principle for urban transformations in Paris and is currently being taken up by many other cities, such as Hamburg, where they are being further developed according to local urban needs (Moreno 2020, 2021). If future developments can only be determined through hypothetical scenarios, then scientific expertise in dealing with complex issues is crucial for the evaluation of options for action in the political decision-making process (Mitchell 2008).

The process of reassessing the spatial demands of road users within available areas seeks a balance between different usage demands and traffic speeds, with the goal of designing safe, inclusive, and healthy streets and squares. The issue at stake here is the establishment of spatial equity in the process of negotiating socially oriented objectives in urban space.

Ways toward the Livable City

The reassessment of traffic and mobility in the social process of the transportation revolution creates opportunities for rethinking public space. In this context, the discourse on equitable land use in the sense of a livable city can have integrating effects and avoid the excess ideological baggage accompanying the narrative of abstaining from and banning automobile use. This can be achieved by incorporating goals that can be consensually agreed upon such as amenity quality, climate adaptation, and environmental protection. For example, climate-adaptive urban planning, which aims at reducing local heat islands and closing hydrological loops, offers tangible added value to quality of life through climate adaptation measures and expanded blue-green infrastructure (Bolik 2019; Winker et al. 2018).

Professional urban planning is faced with the challenge of preserving and further enhancing the respective existing qualities in cities. The transformation of our cities and communities involves, by definition, spatial parameters that pose design challenges. These are highly complex fields of activity that can no longer be mastered using narrowly focused, linear, or sectoral solutions. For example, the need to achieve intermodal efficiency in the design of transfer hubs and to adopt a systemic perspective on intermodal mobility systems (Eckart and Vöckler 2022: 25) increases the complexity of the urban design challenge. A sensible site development concept is just as important as the amenity qualities of the public spaces that benefit the entire neighborhood.

Design concepts aim to address these complex challenges by reinforcing existing qualities and intrinsic potential, mitigating risks, and securing future room for action. Examples of integrated strategies of high design quality can already be found worldwide in projects for climate change adaptation, flood protection, or participatory planning. The diversification of transport infrastructure and mobility cultures is determined by technological possibilities but requires design integration into the urban space and site-specific adaptation if these are to be implemented successfully. This represents a great opportunity for our cities to articulate their own concepts and use these to develop local identities.

As the example of Copenhagen clearly illustrates, the promotion of inclusive and healthy urban development is not only a question of the quality of the architecture but is also an expression of holistic planning that involves all urban stakeholders. It is important to take advantage of the opportunities offered by expert urban planning: in the further development of mobility concepts, in the design of public spaces, and in the development of new typologies and site qualities that will be achievable in the future as a result of new technologies and changing social demands. In addition to the close cooperation between disciplines at different urban scales, it will also be necessary to moderate ongoing social negotiations among different objectives. Only in this way will innovative paths based on research and science develop, as well as have a chance of being accepted and successful in their implementation. Integrative processes, holistic approaches and, last but not least, good design are the keys to a livable city.

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Long-Term Focus Groups as a Mobility Research Method

Petra Schäfer, Dana Stolte, and Nicole Reinfeld

As part of an interdisciplinary research project, a primary objective was to identify the imagery that is characteristic of specific regions in terms of mobility and transport.[01] In order to utilize qualitative methods together with existing quantitative data, a focus group was recruited and deployed for various surveys and workshops. Group consultations provided a means of testing concepts, developing new ideas, overviewing public acceptance of a service, and studying the impact of an initiative, for example. Of particular significance here is the fact that the focus group was assembled at the beginning of the project so that it was possible to work with the same people throughout the entire project. Since the focus group existed for more than three years, this method is referred to in the following text as the *long-term focus group*.

Prototypical applications and scenarios were to be tested with people of different age groups and from different physical environments to gain insights into the effect of designs on individual mobility behavior. In this context, methods were chosen and developed in order to discuss specific questions from the fields of design, traffic, technology, and urban planning. User-specific data was collected and made available to the other project partners, while taking data protection into account. In the end, this new method of mobility research was evaluated.

This essay presents both the participatory work with the focus group and the content-related activities. In conclusion, an evaluation of the long-term focus group method is provided.

Current Status of Research and Research Questions

In addition to social or market research, the focus group method has also been more commonly used in recent years within mobility research as a qualitative or explorative method, as the following selection of projects illustrates.

One application of such a focus group, for example, is to find out about (potential) user views. For this purpose, three different focus groups (»new customers,« »combiners,« and »opt-outs«) were used to evaluate two bicycle rental systems as part of the research supporting the laboratory phase of the pilot project »Integration of public bicycle transport,« conducted by the city of Berlin (WVI 2010). A bicycle rental system was also investigated in the study of the city of Mainz's MVGmeinRad. There, focus groups were deployed to analyze the intermodal use of the bicycle rental system »in combination with bus and train« (Czowalla et al. 2018). In another project titled »Social Science Research on the Rhine-Main E-Mobility Regional Model—User Acceptance and Optimization,« participants in pilot projects discussed their experiences (Blättel-Mink et al. 2011). Interactive focus groups were also utilized as a means of investigating »user demands for individual mobility solutions, how users assess various micro-vehicles and how these can be employed in their everyday mobility« (Pollmann et al. 2018).

Focus groups are also utilized to formulate hypotheses or evaluate scenarios. For example, focus group interviews were conducted to »obtain a basis for formulating hypotheses« (Pecharda 2008). As part of the research project »AVENUE21–Automated and Connected Transport: Evolution of Urban Europe,« focus groups were deployed to evaluate possible scenarios (Mitteregger 2020).

This methodology is also used when social research institutes are engaged to carry out mobility research. For example, the infas Institute for Applied Social Science, commissioned by the automotive supplier Continental, conducted international mobility studies between 2011 and 2018 using focus groups. These studies had alternating focal points and dealt with »the structure of everyday mobility« (infas n.d.).

01 The research project »Infrastruktur—Design—Gesellschaft« (2018 to 2021) was funded by the Landes-Offensive zur Entwicklung wissenschaftlich-ökonomischer Exzellenz (LOEWE) in the German Federal State of Hesse with the following lead project partners: the University of Art and Design in Offenbach (design, overall management), the Frankfurt University of Applied Sciences (transportation planning), Goethe University Frankfurt (mobility research), and the Technical University of Darmstadt (media and communication technology/architecture).

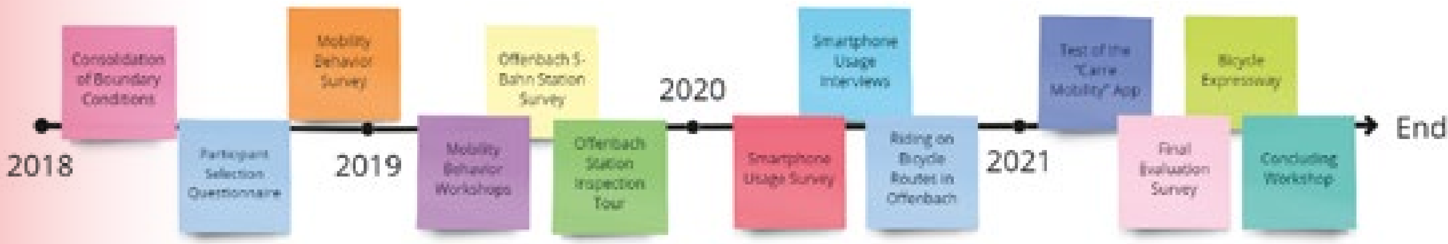

Fig. 1 Timeline of focus group activities (authors' illustration)

In the project discussed below, the utilization of the focus group took place under similar background circumstances as in the aforementioned projects. In contrast to those, however, this focus group was used not only to answer one but several questions over the course of the entire project. Since this method had not been previously applied in such a way within mobility research, the following research questions were investigated:

- What are the advantages of the long-term focus group method for the project?
- What are the advantages of the long-term focus group method for the participants?
- In what ways can participants be motivated to continue their involvement?

Procedure

This essay describes the procedures for assembling the focus group for collaboration, conducting surveys and workshops, and project closeout. The individual steps and activities are represented in ↳Fig. 1.

In the first half of 2018, the boundary conditions for the characteristics of focus group participants were defined (mobile persons living in the Rhine-Main region). The actual recruitment of the focus group began in August with an online survey. The announcement was made via e-mail distribution lists, personal contacts, the press, various newsletters, social media, and other universities in the Rhine-Main area. In December 2018 the selection process was concluded. For the focus group, 232 people were recruited who met the boundary conditions.

The group was comprised of 40 percent women and 60 percent men. The 46 to 55-year-old age group was the most heavily represented, followed by 56 to 65-year olds and 26 to 35-year-olds, each with about 20 to 25 percent. The remaining 30 percent was split between the 36 to 45-year-old, 18 to 25-year-old, and 66 to 74-year-old age groups. Only two people were over seventy-five years of age. Most individuals (97 percent) held a driver's license. Only 0.4 percent of participants said they could not ride a bicycle.

Data protection played an essential role in project implementation. For example, it had to be possible to correlate one person's responses to different surveys. In addition, the plan was only to write to certain people in some cases; for example, just those who had previously taken part in a survey. Nonetheless, the data collected was to be anonymized. For this reason, three-digit personal identification numbers were assigned in the first online survey on mobility behavior. Starting with the number 101, all participants were respectively assigned a consecutive number. To minimize the risk of incorrectly entered numbers, rep-digits, as they are called, were omitted. In the surveys, participants then only had to enter this code and not their name or e-mail address.

In the first workshops held in March 2019, each with between ten and twenty-five participants, not only mobility behavior but also participation expectations for the focus group played an important role. In this way, expectations that could not be met could be eliminated at the beginning and information about the working methods and opportunities in the LOEWE research project could be provided. The expectations of workshop participants can be grouped into the following four categories: personal development, influence on mobility, transformation of transport, concrete positive results. Feedback from participants during the focus group activities was recorded and taken into account when planning further activities.

To strengthen cooperation with the focus group members, regular e-mails were sent to the entire group, including invitations to surveys or workshops as well as reports on the current status of the project—and even Christmas greetings. Incentives were also sent out as a token of appreciation for participation. By being included in newsletters and invitations to events, participants were able to obtain more detailed insights into the research and to become better acquainted with the project consortium.

In the final year of the project, the focus group was invited to participate in a survey and a subsequent workshop. Both served to evaluate the long-term focus group methodology from the participants' point of view.

Summary of Thematic Work and Related Findings

In August 2019, the focus group was invited to an inspection of the Marktplatz S-Bahn station in Offenbach, in cooperation with the Design Institute of Mobility and Logistics at the HfG Offenbach. The inspection tour with nine participants focused primarily on the design of the station. In addition to a previously conducted online survey, the participants were asked on-site which waiting areas on the platform they preferred. Through this it became apparent which factors influenced the choice of waiting areas. Findings from the survey were incorporated into research work at HfG Offenbach (project-mo.de 2021).

In collaboration with computer scientists, a preliminary concept for an app to promote environmentally friendly mobility behavior was tested (Gilbert et al. 2020). This app uses activity recognition via smartphone to record the mobility of users in order to improve mobility analysis by means of concrete mobility data, while at the same time illustrating for individual users their own personal mobility. During the test phase, additional functions were automatically activated. A survey on smartphone use took place in March 2020. Due to the pandemic, subsequent workshops on the further development of the app concept had to be cancelled, but these were replaced by individual interviews via video calls in May 2020. Based on the survey and interviews, a detailed concept for the app was developed (see Reitmaier et al. in this volume).

In road tests of cycling infrastructure such as the cycle streets in Offenbach am Main in September 2020 and the bicycle expressway between Darmstadt and Frankfurt in August 2021, weak points and obstacles, as well as the advantages and attractiveness of these kinds of projects, could be directly evaluated during use. It became apparent that many road users are not familiar with the concept of cycle streets. Therefore, the small section from the focus group that participated also suggested that the rules should be better publicized. In addition, they felt that uniform rules for the design of such lanes would be beneficial. In the case of the bicycle express lane, participants criticized a sign in the middle of the pavement as well as a steep drop at the pavement edge but they especially highlighted the overall ride experience and the lane width as being positive. These results were passed on directly to the FrankfurtRhineMain Regional Association and could thus be incorporated into the further development of regional high-speed cycle lanes.

Focus group workshops were also held to test the Carré Mobility app for interconnecting neighborhoods as part of the »Environmental Mobility Hub« research project. Prior to this, a potential analysis for the mobility platform Carré Mobility had been conducted in the research project of the same name (Schäfer et al. 2021). Workshop participants had the chance to test the app and its functions before its release and to provide feedback. Tests of the app provided information about its user-friendliness and comprehensibility. These

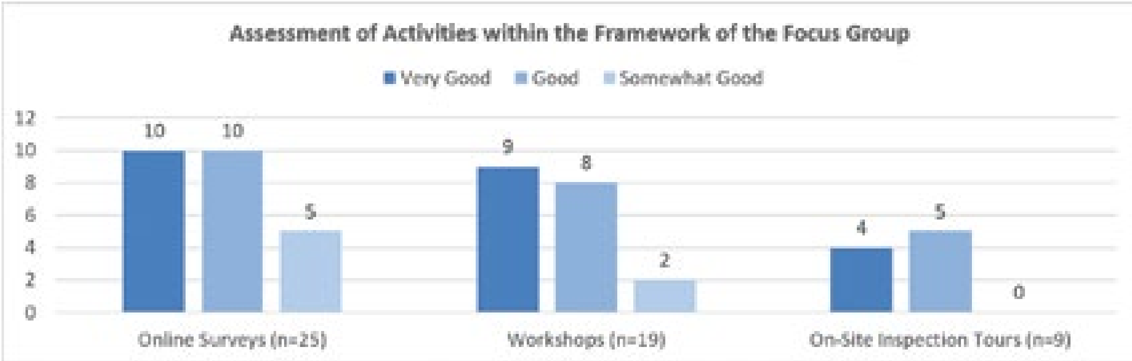

Fig. 2 Assessment of events

findings are being incorporated into the further development of the app in order to adapt it to the needs of future users.

When evaluating and interpreting the results, the fact that the focus group was not representative and that some participants' mobility behavior was very similar was always accounted for.

Evaluation of the Participation Process

A final survey was conducted in June 2021, with all focus group members invited to participate, regardless of whether or not they had contributed. The aim was to find out what people thought about participating in the focus group and in this way evaluate the work done with it. At the outset, respondents indicated whether they had participated in activities such as surveys, workshops, or site visits.

Subsequently, fifty-five people who had not participated were asked about the reasons for their lack of participation. The main reasons given were lack of time, lack of information, distance from home, and other commitments. Twenty-five respondents who had participated in actions during the focus group were able to indicate which activities they had participated in and rate these on a six-point scale (very good to very bad). The assessment of activities was predominantly positive (↳Fig. 2).

With regard to the online surveys, in the open-response box, focus group members praised the design and comprehensibility of the questions, the »interesting and relevant« questions, and the preparation for subsequent workshops and inspection tours. Two respondents criticized the answer choices as being »not always appropriate.«

In respect to the workshops, respondents particularly emphasized the exchange with other participants and the »positive and open« working atmosphere. Respondents approved of the on-site visits as a way of »getting a picture of the situation.« They praised the way these were conducted. One suggestion for improvement was that there should be more intermediate stops.

The assessment of communication, on the other hand, was more mixed (↳Fig. 3). In this respect, available communication channels were used to varying degrees. While (almost) all focus group members were aware of the newsletter and the communication in e-mails, ten people could not remember the Christmas card from the first year of the focus group. About two-thirds of the respondents did not make use of social media.

In the open-comment boxes, respondents praised the e-mails as being »appreciative,« »personal,« and »friendly,« as well as the layout of the newsletter and the opportunity to ask questions. As a point of criticism, one respondent wanted to publish more on the »common social media platforms« and complained that in one instance »communication had broken down.«

Subsequently, the long-term focus group was evaluated as a method of involving interested laypersons in the research. In the process, nineteen respondents rated the method as »very good« and five respondents as »good.« Subsequently, they

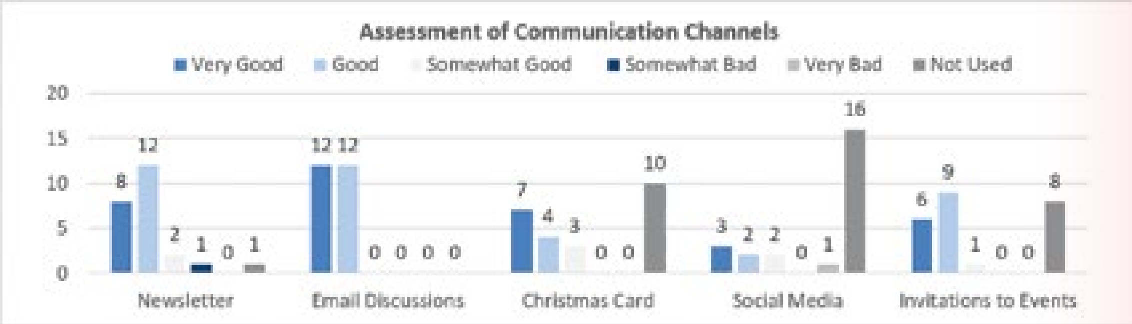

Fig. 3 Assessment of communication (n=24)

provided the reasons for their assessment in the open-response box:

- Change of perspective through the involvement of outsiders,
- Increasing acceptance through the involvement of users,
- Sharing knowledge among focus group participants.

Respondents were then asked to indicate whether their expectations from the start of the focus group project had been met. Ten respondents indicated that their expectations had been met and thirteen people that their expectations had been partially met. The latter were then given the opportunity to highlight which expectations had not (yet) been met. In this context, two respondents mentioned that the COVID pandemic had not had a »communication-enhancing« effect, and two other respondents said that they knew too little about the project results.

Following on from this, suggestions for improvement were made. Respondents mentioned an increase in communication, a shorter project duration, an increase in the number of group participants, the choice of topics, and the desire for more in-person events. At the end of the survey, forty-four people agreed to remain in the focus group to continue supporting the research.

Conclusion

The focus of the project was to recruit and monitor a focus group of residents of the Rhine-Main area for the research network. By means of this group, scientific findings derived from the user perspective were to be obtained by involving interested laypersons. The project concentrated particularly on the long duration as well as the participative work. As a result, the question arose as to the advantages of the long-term focus group method for the project. It was an advantage that the focus group was assembled at the beginning of the research project and as such could be available for the entire project duration. The group could be used as a whole or in different constellations without having to recruit a new group each time. In addition, the participants knew about the project and its goals from the very beginning. That made it easier to deploy the group, since they did not have to be informed about the entire project during the activities, but only about the current status or the respective goal of the activity.

Furthermore, the benefits of this method for participants were explored. By having the opportunity to express their opinions on current topics in mobility design and to test applications, participants were able to influence and help shape research in the field of transportation, to bring the perspective of »outsiders« into the research, and to report from the perspective of users. However, it must always be kept in mind that the focus group tended to be somewhat homogeneous in their behavior and attitude toward mobility. This point was always factored into the analysis. For example, during the tours of the cycling infrastructure, for the most part it was the assessments of those who are bicycle-savvy that were collected. When recruiting the next time, this should be considered more closely, so that the participants differ more in their mobility behavior. People who participated in the final survey also mentioned the transfer of knowledge to lay people as one of the advantages offered by this method. In addition, workshops and on-site visits provided opportunities to get to know the other group members and to exchange ideas in discussions. More in-person events and further opportunities for exchange were mentioned as ideas for improving future collaborations.

Owing to the duration of the project, it was necessary to motivate the focus group over a period of several years. Therefore, ways in which this could be done were investigated. Traffic and mobility are topics that affect almost everybody, and a large proportion of the population consider these almost every day. When the focus is on mobility design, such as the design of infrastructure or applications, user opinion is an essential factor. It is important to involve the focus group in such a way that participants feel they can freely express their judgments and exchange views with other group members. In the final survey, these two points in particular were given a positive assessment.

Due to the significant amount of effort involved in participation, maintaining participant motivation proved to be one of the more difficult issues. Despite constant communication and invitations to surveys, workshops, etc., there was no way to prevent some people from dropping out of the focus group during the course of the project.

In addition, not all participants were equally interested in all activities and research projects. However, the topic of mobility concerns almost all people, which is why in theory all persons from the focus group were potential participants in the activities. Since they could decide whether to participate, however, it was often their particular interest, for example cycling, public transportation, or apps, that played a decisive role. This degree of flexibility and the ability to form small groups for the various activities were only possible because over 200 people were recruited at the outset.

On the whole, it can be stated that the long-term focus group method provides an opportunity to obtain the user point of view over the entire duration of a project, or over several projects, and to test new ideas. This type of focus group can be used in particular for questions that relate to the user's perspective on transport modes or services. This has also motivated some participants from the focus group to continue supporting the research.

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Practice-Led Design Research (I)

Configuring Transit Settings in Public Transportation

Anna-Lena Moeckl, Julian Schwarze, Peter Eckart, and Kai Vöckler

Disciplinary research focused on design pursues different ways of generating and communicating new knowledge. This includes practical design work, which produces knowledge that can be useful not only for the discipline itself but also for other fields; this knowledge is consequently embodied in the design projects. It is also made accessible through explanatory texts and visualizations, as explained in this essay. What is crucial to understanding and assessing the quality of a design project is the elaboration of the conceptual, systemically oriented approach that underlies the design. This design-oriented research perspective will be introduced and further illustrated through design concepts from the field of mobility design.

Practice-Led, Project-Based Research (Research through Design)

Design research distinguishes between three different research approaches: firstly, research *on* design, in which design practice and its results are the object of study (in design theory and history, but also, for example, in art history, sociology, and psychology); secondly, research *for* design, as research in support of design practice, where research and the evaluation of design decisions incorporate research approaches from, for example, the fields of technology, ergonomics, economics, psychology, and sociology, or are conducted through corresponding research collaborations (see the chapters by Schwarze et al.; Albrecht et al. in this volume); and finally, research *through* design as practice-led, project-based research, culminating in a product or system innovation (Frayling 1993; Findeli 2004). The latter process is closely tied to design practice; its research contribution is the design output, which literally embodies this new knowledge. Designing, insofar as it proceeds in a systematic and structured manner, is exploratory, but it differs from scientific research in its focus on the constructive design output, which synthetically brings together the knowledge that has been generated, as will be explained in more detail below.

In principle, the goal of design is to enable new possibilities for perception and action in the application by means of the designed product (object, information, space), as well as to convey meaning beyond concrete usage in relation to the sociocultural context. Design always refers to something that is already there: something given, a circumstance, a problem. A fundamental aspect of any design is that something new is created—an existing state of affairs is transformed into a more desirable one. Accordingly, design is anticipatory, and above all generative (Jonas 2004). Design is enabling. However, the new is not only legible in the degree of product or system innovation (which applies equally to engineering innovations, for example), but also in terms of the extent to which it enables or improves user access to the object, or even creates new systemic access via the product design. In addition, there is the question of how it leads to a new aesthetic experience and to a new semantics (which in turn pertains to the artistic dimension of design). This is in keeping with the dual character of designed products; on the one hand, they are practical products that need to be designed to be functional in their use, and on the other, they are aesthetically and semantically charged products that have to be designed for their effect (Steffen 2011). This constitutes the special nature of the design process; it is highly context-sensitive and situationally oriented, grounded in technical expertise and aesthetic judgment, and at the same time it has to accept uncertainties. After all, the new cannot simply be derived from an empirical analysis.

How can something new be designed? The unique characteristic of design methodology is that a process of reflection on one's own practice takes place during the design work. This is a process that occurs in iterative loops, which resembles a »conversation« between the designer and the object being designed. From an initial assessment and formulation, unexpected resistances and perspectives emerge from the thing being designed, which in turn are incorporated into subsequent design work (on the iterative approach, see Bürdek 1975; on the sociological perspective on a reflexive design practice, see Schön 1983). This iterative procedure also allows for the prototype to be put to the test, so that user feedback can be integrated into the design process. Therefore, this is not knowledge generation in the scientific sense (knowledge that can be deductively derived, explicated, and correspondingly verbalized, objectified, and formalized), but rather it is embedded, tacit knowledge that is rendered visible through the design output (on tacit knowledge, see Polanyi 1966). In contrast to analysis, which breaks down complexity into more manageable parts, design is always propositional and focused on a totality (Redström and Wiltse 2019). Here, the designed entities and circumstances do not become objects and facts but are part of a shared context: design as the conception of a new, enabling context that is mediated through the designed artifact and creates new access opportunities (in this case to environmentally friendly, intermodal mobility) by means of a systemically oriented design approach.

Whether the design process can be reconciled with the concept of scientific research remains controversial (Maldonado and Bonsiepe 1964; Mareis 2011; Steffen 2011; Bonsiepe 2021). The contribution of practice-led design research to the broader definition of research lies in its independent methodology (the advantages and disadvantages of which will not be discussed further here) and its specific research approach, which operates at the interface of artifact and human being and consequently the (social) context of usage (situational, systemic, and contextual orientation). A contextual and systemic design orientation involves the consideration of the initial situation in its entirety, in terms of its relationships and interactions relative to the underlying question and problem (as identified in the initial assessment). The problem then acts as an orienting and structuring principle and marks the boundaries of the design area to be worked on. Based on actual mobility design projects, the section below will demonstrate how systemic orientation leads to a relevant approach to conceptual solutions and to the design proposal.

Design of Transit Settings within Public Transportation

A central challenge for the design of transit settings within public transportation is the barrier and stress-free routing of users through the transportation infrastructure. On the one hand, this concerns the functional requirements of accessibility, comprehensibility, and usability of the transportation system, such as information on routing in conjunction with spatial elements to ensure trouble-free, seamless movement. On the other, this also involves socioemotional requirements that influence, for example, the feeling of safety or the need for privacy while in transit. From a design perspective, the question therefore arises as to how spaces and paths that connect modes of mobility can convey not only functional but also socioemotional qualities. The aim of this design approach is the avoidance of physical and cognitive obstacles to create a »flow« in the movement (as well as in waiting), to create a connective space that is clearly recognizable to users as a coherent whole and that simultaneously facilitates a positive mobility experience (see Vöckler and Eckart in this volume).

The study »Station of the Future–Offenbach Marktplatz S-Bahn Station« is based on a comprehensive analysis of the current situation from the user perspective.[01] Offenbach Marktplatz is a mobility hub that links an underground S-Bahn (suburban train) station via an intermediate level (B-level) with the aboveground city center, the city bus lines, as well as additional sharing services. The analysis was systemically focused on the user experience along the spatial configuration. It became apparent that the connection between underground and aboveground mobility services was inadequate from the user perspective: necessary information was missing at crucial points along the route. The spatial configuration consisting of an underground S-Bahn station and the aboveground urban space makes orientation difficult and involves high stress potential: underground due to the lack of awareness of the upper level and aboveground due to the lack of real-time information. For wayfinding, it is essential that the necessary information for choosing the desired direction can be found at nodes/decision points. Among other measures, the new concept led to the design of an »information cube« that provides mobility information on all four sides. It stands available to travelers on their way from the city center and

Figs. 1+2 Design and implementation: the »information cube« at the S-Bahn station Marktplatz in Offenbach creates a bridge between two mobility systems (local bus and regional S-Bahn systems) by means of an information element that links them in terms of location and design. (Source: Julian Schwarze/DML – Design Institute for Mobility and Logistics, HfG Offenbach am Main)

bus to the S-Bahn and vice versa thus facilitating orientation. Information is arranged according to need for arriving and departing passengers. On the intermediate level between the aboveground urban space and the underground platform, the cube provides a transition between two different information systems: that of the regional S-Bahn and that of the urban bus lines. The amount and form of the information is adapted to the respective positioning in the mobility chain and reacts dynamically to changes, such as cancellations or delays. The »information cube« was designed to create a systemic link between two mobility services, that of the municipal transport services (buses) and that of Deutsche Bahn (S-Bahn), by communicating a sense of cohesion across the physical distance. Information that is positioned and aligned in the proper place can significantly improve transitions between different mobility services (↳Figs. 1+2).

The investigation showed that the waiting situation on the underground platform was perceived as being unsatisfactory in terms of amenity quality and orientation. Therefore, the platform was reorganized with uniformly distributed benches and information pillars, which previously didn't correlate with what was needed for waiting or dispersing along the platform. The conceptual approach taken here considers movement itself, or being mobile, as an overarching experience even when waiting. Another important insight was that waiting should also be understood as part of movement—that is, of being mobile—and thus becomes part of the design problem. This was achieved by

01 The study was commissioned by Deutsche Bahn (DB Station and Service) in 2019. A team of designers (Mervyn Bienek, Kai Dreyer, Anna-Lena Moeckl, Julian Schwarze, and Luke Handon) developed the concept study. Peter Eckart, Kai Vöckler, and Julian Schwarze were responsible for the project. The complete study can be accessed at http://wwwproject-mo.de/zukunftsbahnhof-s-bahn-station-offenbach.

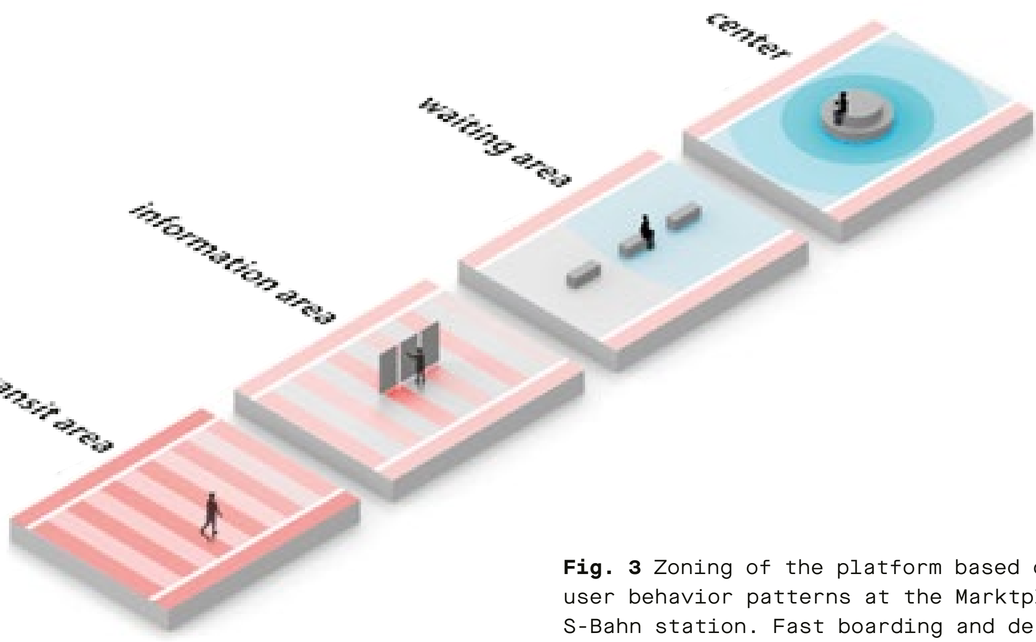


Fig. 3 Zoning of the platform based on user behavior patterns at the Marktplatz S-Bahn station. Fast boarding and deboarding at the beginning of the platform is facilitated, departure information is clustered, waiting zones are created, and better distribution of travelers along the platform is achieved. (Source: Kai Dreyer/ DML, HfG Offenbach am Main)

zoning the platform so that passengers are intuitively guided to transit, information, or waiting areas based on their needs via appropriately positioned and grouped elements such as information pillars, seating, and leaning areas. Stays in these transit, information, and waiting areas are thus spatially separated, which should make the mobility experience more pleasant and less stressful for users (↳Fig. 3). In addition, zoning can result in improved and smoother traffic flow management, which was seen as a further advantage from the point of view of the operator, Deutsche Bahn. These two concepts have been partially implemented and evaluated by Deutsche Bahn. Further conceptual approaches and designs, as developed in the study, can also be included in future projects commissioned by Deutsche Bahn.

How a transfer situation at a mobility interchange can be optimized through design and at the same time allow for a positive mobility experience was the topic of a semester project at HfG Offenbach University of Art and Design in collaboration with Deutsche Bahn. It focused on the underground platforms at the Hauptwache S-Bahn station in central Frankfurt, with the aim of improving access and egress situations at S-Bahn stations in general.[02] Here, too, the question was how to create mobility flows at the Hauptwache station that would be characterized by trouble-free orientation and accessibility for all users. The starting point was the systemic approach, which does not exclusively consider the spatial configuration in isolation, but rather understands the process of changing trains as part of an overall, interconnected mobility that can be experienced by users as unimpeded »flow.« Rather than isolating single factors associated with the study site, the holistic design incorporates and links the interrelationships among product design, information, spaces, processes, and actions. In our view, the positive mobility experience thus created by the design is crucial for the acceptance of mobility systems. Two examples will be used to show how intuitive orientation can be linked to wayfinding

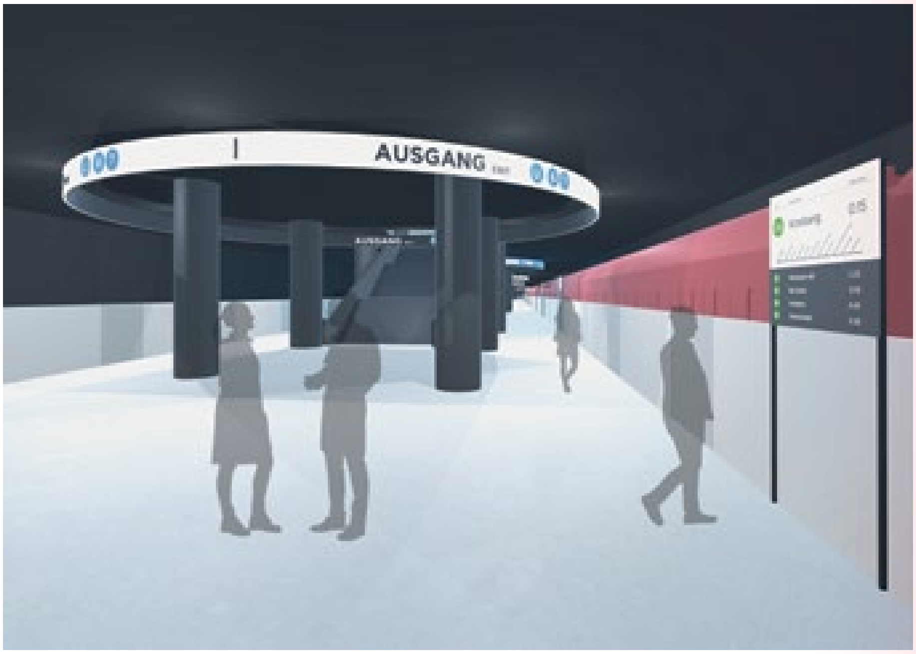


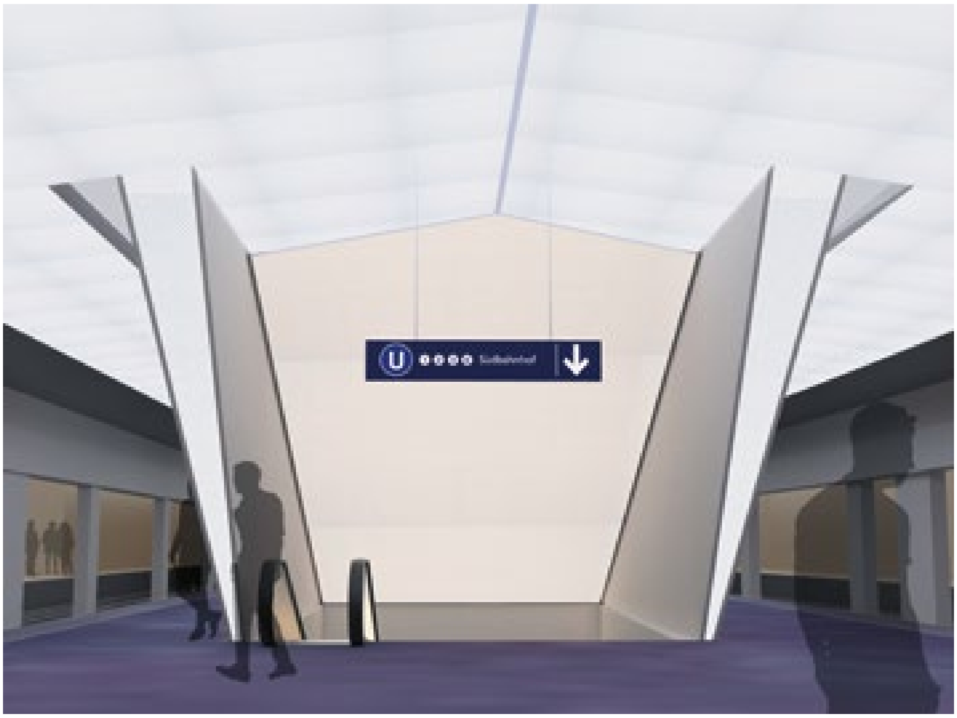
Fig. 4 The »Circulate« orientation system conveys information that can also be perceived from a distance: white information rings point the way out using daylight; blue information rings point to the subway leading down. (Source: Andreas Hildebrand/DML, HfG Offenbach am Main).

information through appropriate spatial configurations and lighting so that the process of changing trains can be perceived without any problem or very much cognitive effort on the part of users. The orientation system »Circulate« (design: Andreas Hildebrand) combines information that is usually separated into grouped elements. The chosen ring shape serves as a spatial orientation point (landmark) and information bearer at the same time (↳Fig. 4). Such an intuitively experienced design, whose information can be read even from a distance, gives travelers a sense of orientation and inspires confidence in their own mobility.

Just as intuitively, the »V.U.I.I.« design (Julia Huisken and Annika Storch) deals with the clear, immediately graspable design of the guidance system, which can be easily comprehended by users even when passing by quickly (»out of the corner of the eye«). This wayfinding system was not conceived separately from the spatial context, but in conjunction with the architectural elements that structure the space. Entrances leading down to the subway symbolically point the way below with the arrow-like design of the architectural elements and their lighting (↳Fig. 5+6).

These design projects are excellent examples demonstrating that design elements can only be grasped in a systemic context. In addition to the consideration of the system that facilitates mobility, however, it is also a question of a coherent user mobility experience. Good design takes into account the functional and socioemotional needs of users and places them at the center. Through design decisions, the configuration influences interaction with the mobility system by allowing users to recognize and comprehend its coherence, while significantly contributing to a positive experience. Thus, new mobility structures are not only more likely to be accepted by people in their everyday lives, but also to be appreciated.

02 The semester project »crossflow_experience« was carried out with design students at the HfG Offenbach University of Art and Design under the supervision of Peter Eckart with Anna-Lena Moeckl and Julian Schwarze in winter semester 2018/2019. Cooperation partners were DB Regio, DB Station and Service, S-Bahn Rhein-Main, and Rhein-Main-Verkehrsverbund.



Figs. 5+6 »V.U.I.I.« incorporates spatial features into the guidance system and provides orientation information that is architectural, graphic, and illuminated. (Source: Julia Huisken, Annika Storch/DML, HfG Offenbach am Main)

Dynamic Signage: The Communication of Distancing Rules in Transit Areas within Public Transportation

During the COVID-19 pandemic (beginning in 2020), informing people about the situation in their own country and around the world became regularly necessary. Given its unprecedented status, the novel virus needed to be understood in new ways and the information conveyed using a wide variety of media and forms. Far-reaching and unprecedented consequences for everyday life followed: behavioral recommendations and rules, mandatory wearing of masks indoors, rapid testing. Above all, the distances to be maintained from other people was, along with the wearing of masks, the most tangible sign of how everyday life was affected by the pandemic. Although distancing of one-and-a-half to two meters was easy to understand, its implementation in everyday life was a challenge. This new knowledge, which was often not yet part of self-evident behavior owing to the lack of an established routine, had first to be integrated into everyday life. How could this important information be communicated in public transit areas so that it was immediately and intuitively understandable for users?

Information is communicated and made recognizable via signs. Signs can be perceived, interpreted, and understood visually, haptically, or acoustically in a wide variety of ways. To communicate distancing rules, for example, signs use figurative language to indicate that distancing must be observed. In addition, there are spatial markings. In supermarkets, for example, floor markings were placed every one-and-a half-meters in the checkout area, or seating areas were cordoned off in public spaces. In a sense, we have become »trained« to maintain a certain distance, and our behavior in public spaces has changed noticeably. Furthermore, the responsibility for communicating distancing rules varied depending on whether the locations were public spaces (for which the public sector is responsible) or privately owned semi-public spaces, such as shopping malls and cafés, or train stations, which in Germany are governed by private law. As a result, there were a variety of generally improvised, frequently incomprehensible, and on top of that, unattractive markings for distance control, which tended to have the negative connotations of hazard markings (↳Figs. 7–11).

During the COVID-19 pandemic, it became clear how new, individual behaviors were continuously becoming more normalized in society, leading to newly learned routines. In this context, signs function as a means of communicating scientific findings to combat a pandemic, here illustrated by the example of changes in everyday routines. The signs that are used often correspond to visual languages that are familiar and can therefore be easily integrated into everyday routines; others are new, and their meanings must first be learned. Local public transportation systems, in particular, have been and continue to be determined by the issue of how much »closeness and distance« users find pleasant or unpleasant—and not only beginning with the pandemic.[03] This is considered a decisive factor for the acceptance or rejection of shared transportation systems. Against this background, the question arose as to how the necessary distancing rules could be integrated into local public transportation, specifically into waiting and transit situations, such that they are not only intuitively understandable but also generate positive experiences. In this way, they are symbolically associated less with danger prevention and more with an aspect of mobility that is taken for granted.

In her student design project »LINE 39«, Annika Storch addressed the problem of communicating information on maintaining distance in public and semi-public spaces, especially at train stations.[04] Based on her own uncertainty regarding the required distancing regulations, she monitored the behavior of passengers at train stations in the

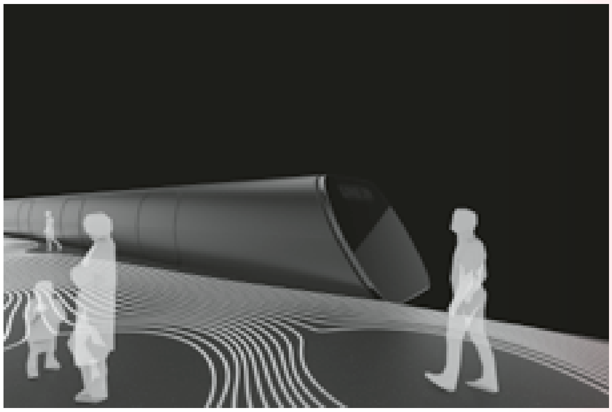
03 Deutsche Bahn's Idea Trains can be cited as an example. These are walk-in design studies that address individualization and privacy on regional trains. Screened or open seating areas allow for privacy or conviviality. A variety of services and differentiated design can serve individual needs (see Deutsche Bahn's Idea Trains: https://inside.bahn.de/ideenzug-db-regio-module/).

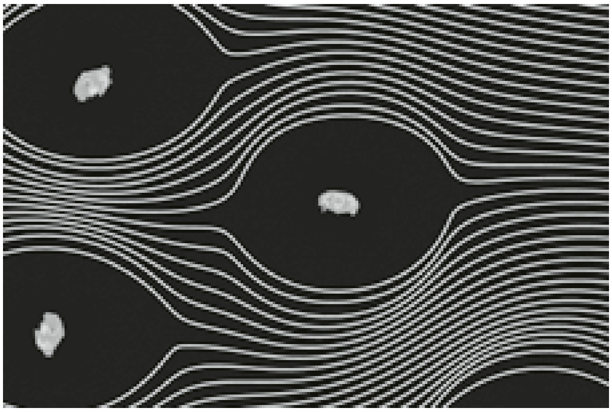
Figs. 7–11 During the COVID-19 pandemic, there was a barrage of improvised information on distances to be maintained, which was often not understandable or even fit for purpose. (Source: Fig. 7 Julian Schwarze; Figs. 8–11 Philipp Kohl/ DML, HfG Offenbach am Main)

Frankfurt area and discovered that it was virtually impossible to maintain the required distance to other people (↳Figs. 12–14).

The fundamental concept driving this design project is the use of visual reactive information that responds to the constantly changing distances between passengers waiting and changing trains on platforms, which at the same time communicates to them the required distances to be maintained. An interactive projection of a grid of lines on the floor reacts in real time to travelers and makes the minimum distance of one and a half meters immediately perceptible. This not only warns other users which areas they should avoid entering, but also allows individuals to easily protect themselves. In contrast to current approaches, which use physical objects such as partitions to separate people, »LINE 39« takes a different track and attempts to make people aware of the distances by means of intuitively understandable signs, namely the reactive lines. This enables them to protect themselves and thus determine themselves how to move around.

If a person walks across the platform, the line grid bulges out in a radius of one and a half meters. If two people walking in alignment with the grid come too close to each other, then the line encloses the respective person and signals that the safe distance will soon become too small. If two people walking against the alignment of the line move



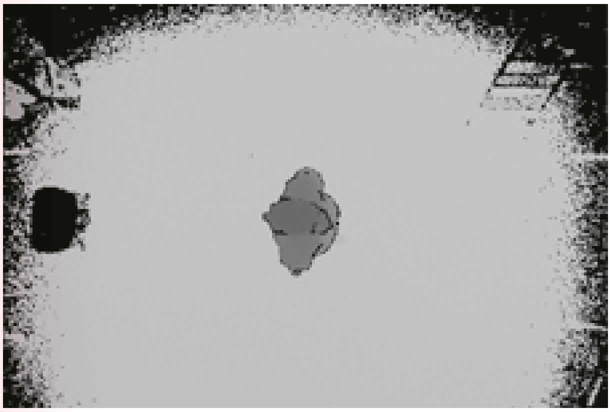


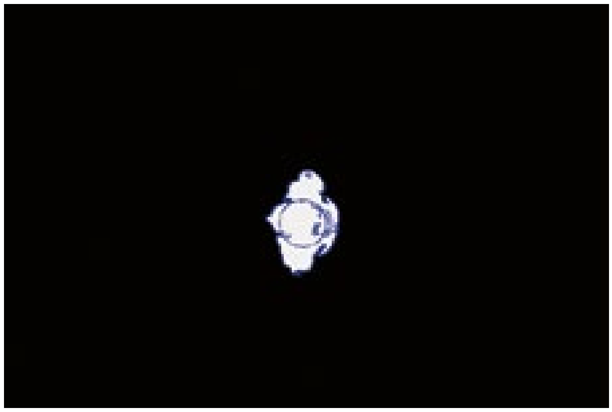
Figs. 12–14 Projected lines react to the passenger volume on the platform and communicate distances between travelers. (Source: Annika Storch/DML, HfG Offenbach am Main)

toward each other, then the lines between the people become denser. This also signals that the distance must be increased. If a person is getting off a train, then he or she is gradually enclosed by the lines and thus incorporated within the system. »LINE 39« makes an otherwise invisible space visible. Technically, this is feasible: a sensor (camera) observes passengers on the platform. A processing code (an object-oriented and strongly typed programming language in the field of graphics, simulation, and animation) interprets this camera data as follows: the pixels closest to the camera are filtered using a threshold filter (a thresholding technique that detects contrasts). A midpoint calculation can then be used to anonymously convert the obtained data into coordinate data. JavaScript (a written code) determines the configuration of the line grid, which is projected onto the platform. Within milliseconds, »LINE 39« shows passengers the correct and currently valid minimum safe distancing between themselves and other passengers (↳Figs. 15–17).

Signs designed to convey information, in this case the pandemic distancing rules, must meet a wide variety of requirements in order to optimally communicate their content. First of all, this is a matter of practical requirements. Travelers moving at varying speeds and high volumes of people at peak times pose particular challenges. By making signs dynamic and reactive in terms of the information they convey, communication can be adapted to the ever-changing use of space, even on an individual basis. An important factor to consider is that cultural diversity in public transportation spaces requires communication that is as intuitive as possible and not hindered by language barriers, for instance. Another important question is how

04 The design project was created as part of the seminar »and now …?« in the summer semester 2020 in the Integrative Design department at HfG Offenbach University of Art and Design (supervisors: Peter Eckart and Julian Schwarze).





Figs. 15–17 1. A Kinect camera (a sensor) observes passengers; 2. a processing code interprets the human(s); 3. JavaScript determines the configuration of the line grid. (Source: Annika Storch/DML, HfG Offenbach am Main)

to impart the credibility of scientifically based distance rules—certainly not through improvised, crudely made distance markers. Information that can be intuitively grasped, which also gives the individual passenger a feeling of being able to autonomously determine the distance maintained, is central to the acceptance of the system. Then there is the aesthetic dimension. The technically advanced, dynamically reactive lighting articulates the space in a way that creates a pleasant experience at the level of perception, while inspiring confidence. Last but not least, the chosen technical design language also has a highly symbolic effect. It stands for progressiveness and fosters acceptance of the scientifically based pandemic distancing rules. But most importantly, a systemic approach has been pursued here. By making the information on maintaining distances dynamic, the transit environment can be experienced in both the transit and waiting areas as part of a comprehensive, intermodal, progressive mobility, which can also be adapted on an individual basis.

Here, as in the design projects discussed above, the specific contributions of practice-led design research become apparent. Starting from a concrete initial situation with a defined question and problem, a systemically oriented design approach leads to product innovations. These are structurally transferable and make the mobility system accessible and more usable, exert a positive influence on the mobility experience, and convey the overall importance of intermodal, environmentally friendly mobility to society.

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Practice-Led Design Research (II)

The Rickshaw Principle—Integrating Innovative Microvehicles into Existing Mobility Systems

Anna-Lena Moeckl, Julian Schwarze, and Peter Eckart

Mobility in urban areas is shaped by structures and parameters that have evolved historically; the built environment determines what kind of transportation is possible. Due to car-friendly city planning, which has been reinforced by relevant organizational and regulatory systems, automobile mobility has been consistently prioritized since the middle of the previous century. The current situation is marked by this prioritization. In existing transportation systems, new mobility services hardly seem to fit in—both in a physical sense and in the minds of users. Therefore, conceptual approaches are needed: how can new and innovative services be integrated into the existing system and how could these services sustainably transform it at the same time? Design research can employ »speculative design« methods through experimental products that explore ideas for the future while critically reacting to the present, thus encouraging new ways of engaging with it (Dunne and Raby 2013). In this way, design research can show how new intelligent, intermodally conceived mobility services (based on current technological capacities) can be contextualized in relation to existing mobility systems. It also addresses the question of how user needs can be taken into account and how the demands of the built environment can be met. The goal is to reduce urban traffic and to create sensible, personalized services for people—services that close the gaps and weaknesses within existing mobility systems while contributing to sustainable mobility.

The design projects presented here articulate different conceptual approaches, showing how product innovations can systemically complement as well as transform existing transportation systems (here with a focus on Germany). The starting point is *micromobility*, a term used to describe mobility with electrically powered, as well as nonpowered, micro and light vehicles (Built Environment 2022). From e-scooters to electrified and nonelectrified skateboards, micromobility includes many light or microvehicles that are characterized by low weight and low spatial requirements. The focus here is on small e-vehicles, which are used individually, but are primarily shared, making their use more efficient and environmentally friendly. In urban environments, they represent a practical link between public transport and individual mobility, which is also referred to as individual public transport (IPT) (Barillère-Scholz et al. 2020). A characteristic feature of small e-vehicles is that they fill mobility-related gaps, especially in the first or last mile. An already established role model exists: the *rickshaw principle*, which can be found primarily in Asian countries, can (when equipped with electric power) be a viable addition to local public transport in Western countries. This small tricycle with the capacity to transport people and goods, also known as a *tuk tuk* in the motorized version, could serve in the future as a model for autonomously driven microvehicles integrated into existing mobility systems as transport modes.[01]

Rethinking Individual Transport

In Germany, as in almost all countries of the world, transportation is dominated by private motorized transport, resulting in considerable burdens on people and the environment (Vöckler and Eckart 2022). The volume of passenger traffic (the distance traveled multiplied by the number of people transported, calculated in passenger-kilometers) increased by almost 34 percent in Germany from 1991 to 2019. Motorized individual transport makes up about 75 percent of the overall passenger transport volume (UBA 2021). This form of transport occurs almost exclusively in passenger cars, which are occupied on average by 1.46 people and are in motion for only forty-six minutes a day (Deutscher Bundestag 2018; Nobis and Kuhnimhof 2017). In the context of society as a whole, the automobile is an inefficient means of transportation. At the same time, from the perspective of the individual, it promises individual mobility that is virtually unlimited in terms of time and space—unless the car and its occupants are stuck in traffic jams, which is often the case due to masses

01 The term *tuk tuk* originates in the Thai language; it describes the sound of a two-stroke engine, which was (or is) the original equipment of motorized rickshaws (https://www.dictionary.com/browse/tuk-tuk).

Fig. 1 The traffic scenario in India. The hop-on/hop-off system of rickshaws is a popular transport mode in India, Pakistan, and Vietnam, among other countries. (Source: Kai Vöckler/DML–Design Institute of Mobility and Logistics, HfG Offenbach am Main)

of cars overcrowding streets in urban areas (see also Vöckler et al. in this volume). What would it be like, however, if individual transport occurred via shared microvehicles in almost constant use, which could adapt flexibly to the needs of the users, rather than via private vehicles, which are often parked in urban areas and left empty? What if they were available on demand, just like on-demand shuttles, but were in fact designed from the user's point of view as part of a comprehensively conceived, intermodal mobility system?

One example of this is the rickshaw mobility system described above, a privately operated three-wheeled microvehicle that is characteristic of Indian mobility culture (↳Fig. 1). In urban areas in India, the rickshaw is an indispensable means of getting around on your own. Unlike taxis, the vehicles are also used for the logistical transport of goods, thus allowing their usage to be more flexible. This type of passenger and goods transport with rickshaws, which is widespread in India, is not only distinguished by its great flexibility and agility in road traffic due to the vehicle's compact design, but also by spontaneous hop-on/hop-off usage in combination with the high availability of these vehicles. From a systemic point of view, rickshaws in road traffic in India are said to function as congestion relievers since they are understood as a self-organizing mobility system, which allows them to penetrate congested areas to a certain extent.[02] In this way, they are comparable to future traffic management systems that will use autonomous transport modes. In such systems, digital communication between the vehicles and their AI-controlled coordination will function as a single unit in order to identify and meet current demand at any given time.

In a future scenario where the rickshaw principle is translated into new mobility services and integrated within existing European transportation systems, urban dwellers and mobility users will benefit equally. Microvehicles, with their high degree of agility and lower environmental impact, will become a self-organizing fleet of vehicles that will be autonomous in the future. They will respond to the requirements of potential passenger mobility and goods transport for individual use and will be designed to this end as a service provision (mobility as a service). As an electric-powered model of the future, the rickshaw principle offers a number of advantages over conventional individual transport vehicles. For example, compact, low-emission vehicles save public (parking) space while also reducing noise and air pollution. Moreover, micromobility opportunities based on the rickshaw principle can be combined with the various levels of autonomous driving: from riding with a driver to fully autonomous, driverless operation, it is possible to integrate these into existing mobility systems (VDA 2015).[03] In addition, autonomous

Fig. 2 Rickshaw mobility has the potential to complement systems in the Western world in the context of autonomous mobility, and thus have a sustainable influence on urban space. (Source: Kevin Lai/DML, HfG Offenbach am Main)

vehicle management and maintenance can be facilitated through artificial intelligence and machine communication between vehicles, in a similar manner to swarm intelligence. Furthermore, the rickshaw principle can be used to flexibly respond to user demand. It optimizes mobility over the first and last mile (the route to and from the respective front door to a public transport mobility service), while further supporting door-to-door logistics. In this way, effectively bundled public transport can be supplemented with (service) options, thus promoting intermodal, environmentally friendly mobility (↳Fig. 2). This positively enhances the convenience of the entire mobility system. Three design projects based on this future scenario are presented below.[04]

How can a transport mode serve spontaneous usage in the first and last mile? Designed as a closed system, the »Pitchē« prototype (design: Amelie Ikas) offers a complementary, continuously available mobility solution. As an autonomous public transport mode, it travels along fixed routes through the urban space (↳Figs. 3+4). It looks like a small cabin that can be boarded or deboarded as needed (according to the hop-on/hop-off principle). However, unlike streetcars, for example, this system has no stops and indeed does not stop. The vehicle remains in continuous motion and merely changes its speed when approaching deceleration zones, thus offering passengers the opportunity to hop on or off in the rear area. During short-distance rides through the city, often used for the first or last mile and done on the fly, the passenger is standing, with the handlebar providing support. The »Pitchē« concept supplements existing (public) mobility services and, in contrast to bicycles, provides enhanced access to individual transportation for persons with

02 These findings are based on a workshop held on March 1 and 2, 2019, at the Indian Institute of Technology (IIT) in Roorkee with Indian colleague Gaurav Raheja (Head of the Department of Architecture and Planning), where the benefits of tuk tuks were discussed.

03 Levels 0 to 5 of automated driving: Level 0: driver only; Level 1: assisted; Level 2: partially automated; Level 3: highly automated; Level 4: fully automated; Level 5: driverless (VDA 2015, p. 14ff.).

04 The semester project »Tuk Tuk_Now« was conducted with design students at the HfG Offenbach University of Art and Design under the supervision of Peter Eckart, Anna-Lena Moeckl, and Julian Schwarze in summer semester 2019. Cooperation partners were Andreas Grzesiek, Steffen Reichert (Mercedes-Benz Advanced Digital Design, Sindelfingen), Markus Mau, and Aeneas Stankowski (Studio Same, Berlin).

Figs. 3+4 The hop-on/hop-off concept taken to the extreme: open and accessible vehicle design is enabled by self-driving systems. (Source: Amélie Ikas/DML, HfG Offenbach am Main)

physical limitations. The special feature of this concept lies in its symbolic effect as well: a continually circulating, open mobility mode that can be intuitively utilized.

»Motus« (design: Oleg Babitsch), another driverless transport system, adapts to the respective mobility situation and the people using it, independent of the route and according to their needs. The design integrates the chassis below the transport surface with seating and roof elements, which together look like a bus stop. This system is distinguished by its open design and ease of use: after you take a seat, the stop becomes a vehicle and drives off (↳Figs. 5+6). So instead of making travelers wait at a stop for the next bus, the platform itself becomes a transport mode that takes passengers to the destination already specified in the smartphone app. Individual transport modules can also be linked together to form larger transport units.

Another way of integrating microvehicles is to think of the transport of goods and people together. The »Cituk« concept (design: Anita Bhuiyan) achieves this synergy: the respective usages of the vehicle are derived from movement and demand. This concept represents a mobility solution that situates the vehicle in two different contexts depending on need and use. »Cituk« is a miniature electric vehicle that can function as a taxi that can be ordered for up to three people along with their luggage, or it can act as a logistical transport vehicle (↳Figs. 7+8). The thinness of the design offers greater maneuverability in crowded streets, efficiently utilized interior space, and the ability to park in less space. In addition, an exchangeable battery at the rear of the vehicle eliminates the need for charging and the resulting vehicle downtimes that disrupt operations.

Understood as forms of speculative design, the three design concepts presented here embody ideas for the future through experimental products that expand the horizons of the imagination. They illustrate how systemic design, in contrast to purely object-focused design studies, encourages integrative thinking about new mobility services. The rickshaw principle can serve as a template for future mobility concepts and be transferred to European conditions. New forms of mobility are imaginable by means of these new approaches, which enable diverse and, above all, individual modes of use. As a complement to existing public transport and cycling services, these concepts address different user needs, for example, by offering greater autonomy due to their constant availability. They represent a kind of platform that enables autonomous movement: independent of ties to a personal vehicle and without its purchasing costs,

Figs. 5+6 A station composed of vehicles: mobility is seen as a process in this design. Public space, waiting, and moving on the road all merge. Will waiting become totally unnecessary in the future? (Source: Oleg Babitsch/DML, HfG Offenbach am Main)

it is also free from the need to register and order an on-demand or ride-sharing service. Further, the COVID-19 pandemic also shows that mobility needs can suddenly take on a different set of priorities, for example, a move toward smaller driving units with fewer or no passengers (Heineke et al. 2020). This desire can be met using the concepts described above and still be sustainable. When developing these ideas for the future, economic concerns were initially excluded, which would naturally have to be considered in further development.

Systemic design approaches address existing transport systems and connect the »new« with the seemingly »familiar.« The design of microvehicles at the interface between system and users, allows not only for (new) applications, but also communicates their significance as a mode of jointly shared, sustainable mobility. The focus is not only on optimizing the mobility system in the sense of increasing efficiency, but even more on the question of how acceptance can be won for this form of micromobility—thus resulting in a gain for the future of (urban) sustainable mobility.

Figs. 7+8 Logistics and mobility conceived together: how can both sets of requirements be based on one system, thus avoiding empty runs and waiting times for transport vehicles? (Source: Anita Bhuiyan/DML, HfG Offenbach am Main)

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Active Mobility

Healthy Blue Spaces

The Frankfurt Riverfront from a Perspective of Urban Design and Health

Martin Knöll

In cities, rivers can contribute significantly to quality of life. The transformation of riverfront areas in Germany from transit zones of the car-friendly city to spaces of movement and encounter for pedestrians and cyclists is a complex and protracted process. In many cities, main traffic arteries interfere with integrated urban development, creating barriers for nonmotorized, physically active mobility. Frequently, the rivers themselves are federal waterways, meaning that responsibility for them lies not with a municipality, but with a federal agency, which complicates planned modifications of riverfront zones. Involved as well are growing demands for flood protection and climate adaptation. Finally, transformations in commerce and remote working represent a fundamental shift in the utilization of downtown areas, and this includes open spaces and public ground-floor zones along downtown riverfront areas. Why, then, address the promotion of health and mobility as an additional aspect when designing downtown riverfront zones?

In cities, large, interconnected surfaces of water, our so-called blue infrastructure, contribute substantially to the promotion of health and to climate adaptation. A »blue space« is defined as an outdoor space whose identity is shaped by bodies of water, because it is either physically accessible or perceptible in audiovisual terms. Examples include coastlines, riverbanks, lakes and canals, and squares with pools or fountains. These offer numerous possibilities for coming into contact with water on a daily basis: people may enjoy the sight, sound, smell, or feel of being near water; they may be active on or near water, by cycling, jogging, swimming, rowing, sailing, or traveling via water taxi. Blue spaces therefore feature a multitude of health-promoting amenities that enhance the quality of life; they can even be quantified in relation to the increased life expectancies of local residents (Roe et al. 2021).

The term *walkability* refers to the potential of a built environment to promote active bodily everyday mobility in the general population (Bucksch et al. 2014). In general, we distinguish between five different dimensions: there is the *density and diversity* of utilizations, the *accessibility* of destinations, the *distance* to the public transport infrastructure, and the *design* of urban space (Ewing and Cervero 2010). From the perspective of urban planning in Germany, walkability is being discussed to an increasing degree against the background of climate protection, as well as of the enhancement of the urban fabric (Tran 2018). At this point, however, there are very few up-to-date studies on the reconfiguration of downtown riverfront zones in major German cities. The aim of this essay is to elaborate relevant structural aspects as well as planning strategies designed to optimize the positive public health impacts of blue spaces. Investigated for this purpose, with reference to the case study of the Mainkai in Frankfurt, Germany, are the value and the role of walkability in municipal planning instruments, as well as structural and programmatic developments over the past thirty years.

Background

Frankfurt has 765,000 inhabitants and is an international financial center, trade fair venue, and mobility and internet hub. Approximately 380,000 people commute daily into the center of the Rhine-Main Metropolitan Region, which has 5.8 million inhabitants. The modal split is 33 percent via motorized individual transport, 21 percent via public transport, 26 percent via pedestrian travel, and 20 percent via bicycle (Stadt Frankfurt am Main 2020). This positions Frankfurt in the middle range for German cities with regard to the share of active mobility (see Buehler et al. in this publication). Frankfurt has seen a steadily rising number of overnight stays, around 11 million involving 6.2 million guests in the year 2019, with the highest share of international guests in Germany, and a large number of additional day visitors (Stadt Frankfurt am Main 2021). Many of these visit Frankfurt's recently reconstructed and unveiled old town, the historic Römer market square, the museums of the downtown area, and the adjacent northern riverbank area of the Main River, known as the Mainkai (↳Fig. 1).

Alongside streets, walkways, squares, green spaces, parks, sports facilities, and cemeteries (19.5 percent), as well as forests and groves of

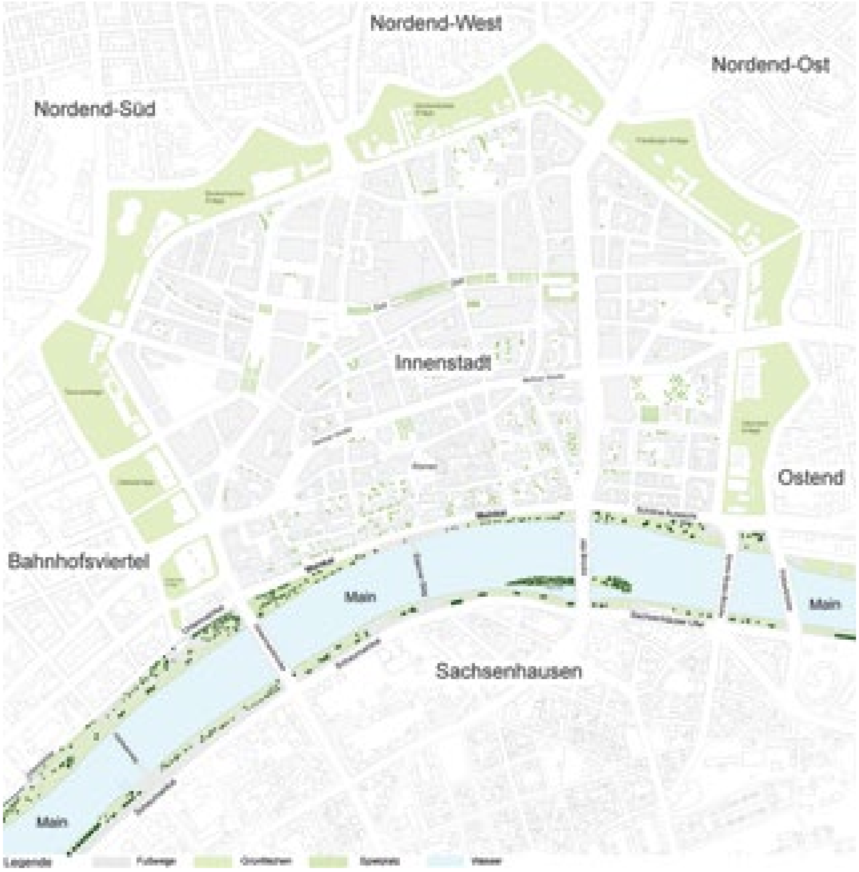

Fig. 1 Map of Frankfurt's downtown (author's depiction)

trees (15.9 percent), approximately 2.2 percent of Frankfurt's publicly accessible spaces (amounting altogether to 36.7 percent of the developed land) consists of bodies of water such as harbor basins, watercourses, and standing bodies of water. This is a far lower proportion than cities such as Hamburg (7.6 percent), Berlin (6.6 percent), and Cologne (4.8 percent), and is comparable with Dresden (2.1 percent), but somewhat higher than Munich (1.4 percent) (Bundesstiftung Baukultur 2021). In urban Frankfurt, the Main River has a width of 120 meters. By comparison, the river has a breadth of 350 meters in Cologne's city center.

The Beginnings

Located near the former ramparts of the city center, which is referred to as Nice for its mild inland climate, was Mainlust, an island with tourist cafes originally separated from the mainland by a tributary (↳Fig. 2). Arriving later were bathing boats, and around 1900, riverside bathing areas, where generations of Frankfurters frolicked (Blecken 1993). Only the last third of the twentieth century saw a renewed interest in reshaping the riverfront zones for the sake of greater cultural, leisure, and recreational use. In Frankfurt, however, this process has been slow. While the downtown shopping mile was transformed into a pedestrian zone during the 1970s, parts of the southern riverbank continued to be used for parking cars well into the 1980s (Wekel 2016).

The rediscovery of the Main River began in 1978 with the origins of the Museumsufer (Museum Embankment) under the motto »Culture for All,« and continued in the 1980s with the project known as Stadtraum Main (Main River Urban Area), which included plans for residences, shops, and promenades in connection with the planned Olympics bid for the year 1992. To begin with, residential buildings with direct waterside locations were created on Westhafen, in the vicinity of the European Central Bank on Osthafen, and on the

Fig. 2 View of Frankfurt with the Mainlust island, prior to the filling in of the tributary known as the Kleiner Main in circa 1858 Quelle: Historisches Museum Frankfurt

Sachsenhausen side. Pursued with the Museumsufer was a concept that propelled the rediscovery of open space along the water through the networking of cultural facilities on both sides of the Main (Wekel 2016). On the Sachsenhausen side, the green areas at the level of the Museumsufer along Tiefkai, redesigned during the early 2000s, have become popular spaces for movement and amenities. Located close to the riverside between the Eiserner Steg (Iron Bridge) and Friedensbrücke are thirteen museums, with an equal number accessible by foot from both sides of the river. Beginning in 2007, all of these institutions have presented themselves collectively as the Frankfurt Museumsufer and attract more than 2.5 million visitors annually (Kulturamt Frankfurt am Main 2021).

Some of the freestanding museum buildings are former upper-class villas; others were designed beginning in the 1980s by internationally renowned architects (Burgard 2020). Discussed in the beginning were two divergent concepts. The Speer Plan of 1976 envisioned a »museum park,« with motorized traffic diverted in an east–west direction along Berliner Straße at a considerable distance from the Mainkai. This concept envisioned an integrated landscape, protected from traffic, on both sides of the Main River. Going beyond the riverfront zone itself, it was to have encompassed the publicly accessible open spaces of the museums as well (↳Fig. 3). Instead, in addition to Berliner Straße (four lanes) and the Mainkai (three lanes, 20,000 autos daily), two main traffic arteries along an east-west axis were built. Both of these palpably segregate the riverfront, reserved for pedestrians and cyclists, from the city center.

Advent of Transformation

The city center development concept of 2010 attests to the disintegration of portions of the downtown and the riverfront area as a consequence of the heavy burden of motorized traffic. Emphasized here was the diversity of urbanistic forms (highrises, row houses from the 1950s and 1960s, timber construction), as well as programmatically (commercial, consumer-oriented, culture), which gave rise to divergent identities such as the banking district and the old town. These were to be strengthened further by future development. It also became

Fig. 3 The Leitplan Museumsufer (Museumsufer Master Plan) of 1976 shows a cohesive landscape zone as a component of Frankfurt's green and blue infrastructure. (Source: AS+P Albert Speer und Partner GmbH)

clear that there existed few route connections along the north–south axis. Proposed then was an extensive network of routes for pedestrians that would span the downtown area in combination with a network of cycling paths that would feed at selected points into cycle streets (along Berliner Straße, for example). This network for active, everyday mobility was to have been supplemented by a uniformly shaped, integrated circular route through the green spaces of the former city ramparts. The relocation of streetcar stops, the partial limitation of access for private vehicles, and the creation of additional bus lines were intended to improve the traffic infrastructure along the north–south axis. The redesign of the Mainkai was presented as a recommendation for action that would fulfill two aims: first, it would reinforce the identity of the lower old town, oriented toward the river, and secondly, it would strengthen green mobility (Stadtplanungsamt Frankfurt am Main 2010). This meant that the city center concept of 2010, which intended to provide a solid point of departure for a movement-friendly riverside, was firmly anchored in the five dimensions of walkability.

The Current Situation

In the late 2010s, the redesign of the Mainkai was taken up again against the background of discussions concerning climate adaptation and quality of life in Frankfurt. This is evident, for example, in the vision of the downtown open areas as surfaces for movement and encounter, with the Main River as a central linchpin (↳Fig. 4). In contrast, the current situation is sobering. At the level of the central pedestrian crossing Eiserner Steg (Iron Bridge) and the Alte Brücke, the Main River is characterized by residential buildings with dispersed cultural and gastronomic amenities. In open areas, these are supplemented by additional gastronomy and kiosks, as well as boat moorings. Together with the offerings of the old town, this leads to notable density and a variety of destinations that are reachable from the Eiserner Steg on foot. Alongside the main arteries that arrive through the Alte Brücke and the Untermainbrücke, the network of routes toward the north and the city center is shaped by the connection across the historic market square (Römer). The numerous pedestrian routes in between are ancillary, and

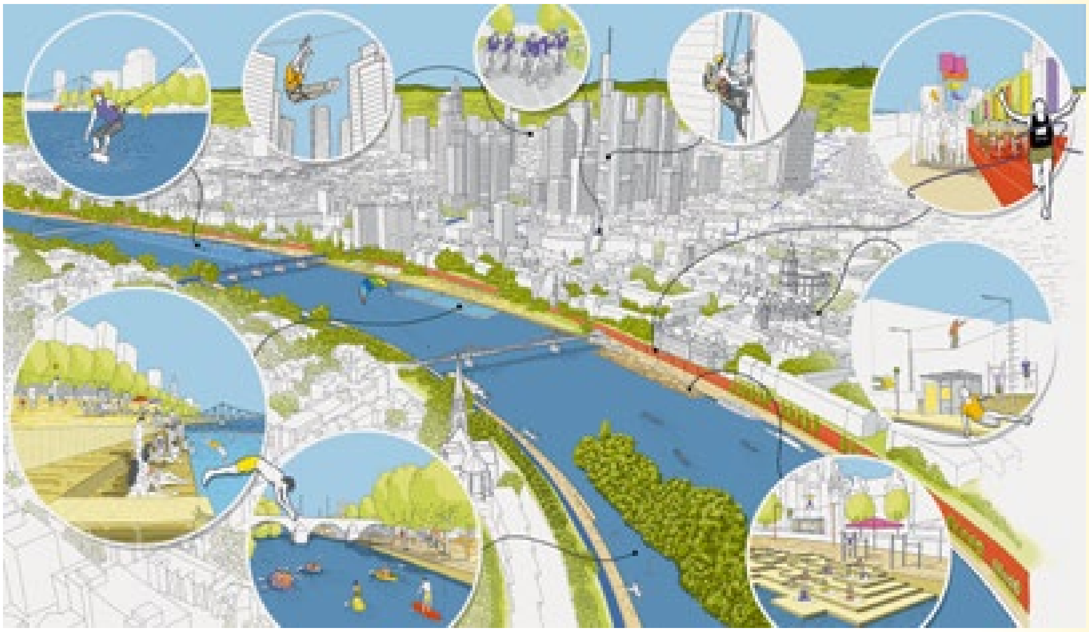

Fig. 4 Frankfurt am Start—Sport findet Stadt (Frankfurt at the Start: Sport Finds City) (Source: AS+P Albert Speer und Partner GmbH)

are used far less frequently (Pandit et al. 2020). Accessibility via public transport is provided via streetcar stops and a subway stop in the old town, as well as a bus stop on the opposite side of the river. Depending upon the specific location, these lie up to 500 meters from the Mainkai, which can already confront mobility-restricted individuals with challenges. The Mainkai itself has no public transport stops. With regard to the promotion of movement and accessibility, the design of urban space here has obvious gaps. With its marked gradients leading from the Mainkai to both bridges, the topography presents an impediment for those with restricted mobility. Only the Eiserner Steg is barrier-free (it can be reached via elevator). The play and green areas at the bridge heads are used heavily, but dominant along the Mainkai are areas paved with material such as asphalt. In some areas, orientation is a challenge as well, given the absence of continuous guidance or lighting systems (Knöll et al, 2020).

A much-heralded transport and urban planning experiment was conducted in Frankfurt between July 2019 and October of 2020: the three-lane roadway of the Mainkai was temporarily closed to motorized traffic. Recorded during this stoppage—which coincided to a large extent with restrictions related to the COVID-19 pandemic—was an up to 40 percent increase in bicycle use, a 20 percent increase in wheelchair users, and 1150 percent more children cycling independently. Registered as well was heavier use by pedestrians along north–south connections, which was distributed uniformly throughout all routes. In green areas along the Main River there were a greater number and diversity of leisure activities, engaged in for more extended periods of time, including sports, picnicking, and recreation (Pandit et al 2020). In November of 2020, the street was reopened to car traffic, with the result that by July 2021, the use by cyclists of the Mainkai had fallen again to the levels recorded prior to the experiment of 2019 (see Pandit in this publication). These figures however do not take into account that in late July 2021, one lane formerly used by motorized traffic was converted into a cycle street.

One objective of the Integrated Urban Development Concept (ISEK) Frankfurt 2030+, which appeared in June 2019, was to increase the share of cyclists, pedestrians, and public transport use, within the modal split for Frankfurt. Among other things, this is to be achieved through a reconfiguration of the street space, as well as through the development of public transport options and bicycle routes. An additional aim is the promotion of affordable living space (to include existing housing

Fig. 5 A future design scheme should be attentive to climate adaptation through desealing and water retention surfaces; it should also have the potential to create additional amenities along the Mainkai through greater interaction with (rain)water. (Design concept: Emilia Kühn, Muriel Stemmler | TU Darmstadt)

stocks), and the qualification of open areas in the city center. The »continuing redesign of the Main riverbank,« which includes a lighting concept, is part of the plans of Frankfurt 2030+ (Stadtplanungsamt Frankfurt 2019). This points up the recognized need for further action to improve mobility and amenity qualities along the Mainkai.

Conclusion

It appears unlikely that many of the positive effects that accompanied the temporary closure of the Mainkai in 2019 and 2020—including an increase in active mobility, improved connections to the city center for pedestrians and cyclists, and heightened use of green areas—will be achieved with cars retruning to Mainkai street and given the current allocation of space. Improvements for bicyclists can be expected from the cycling lane, but this will need to be evaluated scientifically over some time. Future solutions need to go further. Common use by cyclists and motorized vehicles of the street as a shared space could make a substantial contribution to further reducing traffic speed along the Mainkai as a whole. The paving material should be redesigned as a visually unified movement and encounter zone, with zones for pedestrians clearly recognizable for people with visual impairments and according to the two senses principle. A decisive renaturation of the asphalt roadway that is freed up in this way, with far-reaching desealing and dispersed shady areas with trees, would make the Mainkai more responsive to the needs of pedestrians. Necessary as well is due consideration to the reprogramming of selected ground floor zones for the sake of increased public use. In coordination with the agencies responsible for historic preservation, it should be possible to open up buildings toward the Mainkai; outdoor gastronomy and informal cultural uses should also be strengthened, with the aim of establishing and invigorating additional amenity qualities along Mainkai. Inherent in the concept of the Museumsufer (Museum Embankment) is still unused potential—here, it is a question of taking advantage of additional spaces in the downtown area, including underutilized office space and open spaces. In this regard, Burghard (2020) mentions, among other things, the requirements of the Museum of World Cultures, which is currently attempting to procure its own premises.

Worth considering for the sake of improved accessibility to the Mainkai is an additional public transport connection to the riverside. One interesting option could be the use of self-driving minibuses, but they would need to be integrated into the above-described spatial reconfiguration and into an overarching mobility concept for the city center based on limited car traffic, especially they are to enhance accessibility for individuals with mobility limitations. Conceivable as well might be water taxis as an integrated component of Frankfurt's public transport system, of the kind already in use in Hamburg and in London, where it is used to link together the museums that are set along the Thames.

It would also be useful to adapt the design of riverway areas directly along the banks of the Main to the altered and decelerated velocity of pedestrians, including those with restricted mobility and parents with small children. The new requirements described here highlight the need for a supplement to the guiding design principle of a paved, urban Hochkai (high quay). Increased interaction with the waterway along Mainkai would promote enhanced mobility and public health. This could be achieved through a far-reaching desealing of open spaces, as well as through hybrid concepts that are analogous to plans implemented in Rotterdam and Copenhagen. Specifically, this means that during dry periods, sport activities or social encounters could take place in the empty retention basins with seating areas along the edges, as well as in shady zones created by trees; during periods of heavy rainfall, in contrast, they serve as storage facilities for rain water, ready to interact with for pedestrians (↳Fig. 5).[01]

Although the planning instruments of the city center development concept and in the Frankfurt 2030+ masterplan have been structurally anchored in values of walkability since the 2010s, actual implementation continues to fall short of objectives. With the traffic experiments along the Mainkai, the difficulties and potential of city-center blue mobility zones came strongly into focus. Urgently required now is genuine follow-up on the positive dynamic for active mobility, along with an experimental testing approach and scientific verification of interdependencies. The accompanying controversy and passionate discussion, as well as the decision to reopen and, from August 2022, close Mainkai to cars during school holidays, evening hours, and weekends, highlight the necessity for supplementing traffic experiments with formats such as the »real-life laboratory.« In addition to supplying information and encouraging participation they investigate the potential added value for the citizens and render it concretely tangible in optimal ways. This is shown elsewhere by temporary interventions, even with more minimal investments, which clearly demonstrate an immediate effect on the bodies and well-being of residents (Roe et al. 2019). Expedient in this situation would be strengthened transdisciplinary exchanges between citizens and experts from the realms of politics and science, including planners and architects. The shared goal should be to better integrate the long-term planning aims and visions with incremental and yet powerful temporary interventions and scientific evaluations.

01 Further selected results of the urban planning concept »City Center of the Future« can be viewed at https://www.architektur.tu-darmstadt.de/urbandesign/lehre_udp/sose_2020_udp/innenstadt_der_zukunft_ergebnisse.de.jsp (accessed on March 8, 2022).

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Cycling and Bicycle Planning in Frankfurt am Main and Washington, DC

Ralph Buehler, Denis Teoman, and Brian Shelton

The bicycle is a healthy and sustainable mode of transport. Cycling produces no noise or air pollution, and utilizes far fewer nonrenewable resources than motorized transport. In comparison to the automobile, the bicycle requires only a fraction of the space required for driving and parking. Virtually anyone can afford to own a bicycle, which costs private households and public funders far less than either private vehicles or public transport. The energy required for bicycling comes directly from the cyclist. Daily cycling means engaging in regular physical activity and contributes to aerobic fitness and cardiovascular health while protecting from obesity, diabetes, and a variety of illnesses.

Over the past two decades, Frankfurt am Main and Washington, DC, have successfully promoted cycling, and have redesigned their transport systems to make the bicycle an attractive component of mobility offerings. In both cities, this meant a break with the car-oriented planning of personal transport that had prevailed since the end of World War II. In contrast to well-known cycling cities in the Netherlands, neither Frankfurt nor Washington could have recourse to a tradition of cycling or of bicycle planning. This essay discusses the transformation of the transport system, as well as of mobility behavior and transport policies in both cities. The information contained in this text was drawn from interviews with bicycle planners, as well as from analyses of plans, transport concepts, and other publications. To begin with, there is a brief comparison of the two cities, as well as of cycling and mobility behavior overall. We focus on the key considerations that led to the successful promotion of cycling. We conclude by considering prospects for the coming years.

Background, Mobility Behavior, and History

Frankfurt and Washington, DC, have comparable population sizes (765,000 and 705,000, respectively). The municipal area of Frankfurt is however around 40 percent larger, so that population density in Washington is approximately one-third higher (4,000 versus 3,000 people per square kilometer). Both cities have seen strong population growth in recent decades (up 14 percent) (MWCOG 2021; Stadt Frankfurt 2020). Both Frankfurt and Washington are affluent cities, with high average household incomes, and a comparatively high turnover of residents. Both cities are the economic and employment centers of large metropolitan regions, with numerous commuters from the surrounding areas: around 550,000 people commute daily to Washington, the capital of the US government, compared with around 400,000 in Frankfurt, one of Europe's key financial centers (MWCOG 2021; Stadt Frankfurt 2020). Given the absence of high-rises and a cityscape designed by Pierre L'Enfant, Washington, makes a more »European« impression than many North American cities. Conversely, given its skyscrapers, Frankfurt is often referred to as the most »American« city in Germany.

Frankfurt has a lower rate of car ownership per 1,000 residents than Washington (470 versus 510). The average travel distance (6 km) and travel time (21 to 24 minutes) are comparable for both cities (MWCOG 2021; Stadt Frankfurt 2020). In Frankfurt, a smaller number of trips involve private vehicles (33 percent of all trips in the year 2018, compared with 45 percent in Washington for the same time period), and a larger share involve public transport (21 percent versus 16 percent in Washington). Roughly the same proportion of residents in both cities travel regularly by foot (26 percent in Frankfurt versus 29 percent in Washington), but bicycle use is more frequent in Frankfurt (20 percent versus 5 percent in Washington) (MWCOG 2021; Stadt Frankfurt 2020).

In comparison with other German cities, Frankfurt's modal split for bicycles lies in the middle range: it is comparable to Leipzig (21 percent), Dresden (20 percent), Mannheim (20 percent), and Berlin (18 percent). Frankfurt's proportion of daily trips by bicycle is higher than in Dortmund (6 percent) and Stuttgart (7 percent), but notably smaller than in cycle-friendly cities like Münster (39 percent) and Karlsruhe (35 percent). Washington's bicycling modal split for travel to work is higher than in other large US cities such as Miami (1 percent), New York City (1 percent), and Denver (2 percent), and is comparable to Minneapolis (4 percent) and Portland, OR (7 percent), but markedly lower than small cycle-friendly cities like Davis, CA (19 percent) and Boulder, CO (12 percent).

The number of trips covered by bicycle has increased since the late 1990s in both Frankfurt and Washington: from around 1 percent to 5 percent in 2018 in Washington, and from around 6 percent to 20 percent in 2018 in Frankfurt. The increase in cycle traffic between 2000 and 2018 is also reflected in bicycle counts for both cities: an increase of 320 percent of cyclists crossing bridges crossing the Potomac and Anacostia Rivers in Washington, and an increase of 250 percent along the Innere Kordon in Frankfurt (Alleenring/Mainbrücken) (DDOT 2021; Stadt Frankfurt 2018).

Like other German cities that were partially destroyed during World War II, Frankfurt was rebuilt in a car-friendly style, with broad streets and ample car parking. Moreover, streetcar lines were decommissioned to generate space for automobiles (Müller-Rämisch 1996). In Washington, too, planning measures prioritized the private automobile during the postwar era. This included the broadening of streets, the construction of urban freeways, the creation of adequate parking spaces, and the complete elimination of the streetcar system in 1962 (Schrag 2015).

During the 1970s, the energy crisis and growing environmental awareness had a major influence on transportation planning in both cities (Müller-Rämisch 1996; Schrag 2015). Frankfurt had inaugurated its first car-free pedestrian zones, where bicycles were forbidden as well, and had installed narrow (from today's perspective) cycling lanes along sidewalks (generally intended to allow children to cycle to school). Often, these bike lanes had no downward slopes at curbs, and drivers often had difficulty seeing cyclists at intersections (Bloecher 2021). In Washington, the first cycling plan was published in 1976 (Buehler and Stowe 2015; DDOT 2005). During the 1980s and 1990s, however, its objectives were for the most part not implemented. Most of the progress was achieved through the construction of mixed cycling and pedestrian trails in parks.

The Beginnings

During the 1990s, Washington, had no cycling planner, and cycling played no role in transport planning. Constructed on a regional level were further mixed cycling and pedestrian shared-use trails, mostly in government parks, or along new motorways and federal highways in the surrounding area (Hanson and Young 2008). In Frankfurt, the position of a bicycle planner was created in 1991 (a novelty for a large city), along with the introduction of additional bicycle-friendly measures (GSA 1995). Pedestrian zones were opened to cyclists. During the 1990s, Frankfurt participated in a successful nationwide pilot project that allowed cyclists to ride against the direction of motorized traffic on one-way streets located in traffic-restricted areas. The city inaugurated its first cycle street, with cyclists having priority over motorized traffic. Cycling routes were also opened up in green belt areas. Within the city, cycling routes were identified for future development; these were planned for road spaces rather than sidewalks. Bicycle parking facilities were created at local public transport stops (Bloecher 2021). Following the arrival of a new municipal government in the mid-1990s, most cycling projects were suspended or pursued at a reduced pace (Bolle 2021). By the late 1990s, Frankfurt—like Washington, DC—no longer had an independent cycling planner.

New Departures toward Promoting Cycling

With the new millennium, the situation for cycling changed in both cities. In Frankfurt, cycling became a component of the new overall transport plan for the first time. The plan, published in 2005, included a cycle-friendly scenario that envisioned seeing 15 percent of all trips covered by bicycle by the year 2015 (Stadt Frankfurt 2005). In 2006, the governing coalition, composed of the CDU and the Greens, adopted this as a political objective (Hochstein 2021; Lanzendorf and Busch-Geertsema 2014).

Given that the planning of a comprehensive cycling network had failed during the 1990s due to budgetary and time constraints, it was now resolved that in the future, cycle travel would be integrated into the daily decision-making mechanisms related to transport planning and transport engineering (Bolle 2021). Cycling was to be given due consideration as often as possible when it came to everyday street renovations and other relevant projects. Step-by-step, as an ordinary mobility resource, the bicycle became an accepted component of transportation planning in Frankfurt—and cycling became more attractive as a result. Moreover, additional one-way streets were opened up to cycle traffic in both directions, bicycle parking was expanded, and the bicycle was promoted as a convenient and efficient transport resource for all user groups (Lanzendorf and Busch-Geertsema 2014; Bautz 2011). Not just substantively, but organizationally as well, cycle traffic was reorganized throughout the city. Created in 2009 in place of a single bicycle planner was a Cycling Office, which was located in the Transport Department, and was positioned as an interface between transport planning, transportation construction, and the implementation of transport-related measures (Bolle 2021; Bautz 2011).

In 2001, a cycling planner was again appointed in Washington, DC, as part of an initiative designed to enhance quality of life in the city. The first milestone was the publication of a Bicycle Master Plan in 2005 (DDOT 2005). The aim of the plan was to construct more and better cycling infrastructure, to implement bicycle-friendly measures, to expand bicycle training and education in schools, and to increase the promotion of cycling and bicycle safety. By 2010, 3 percent of commuters would hopefully travel by bicycle, and by 2015, 5 percent. In Washington as well, the cycling planner was positioned as an interface between transport planning, transport, construction, and overall urban development. As in Frankfurt, the master plan served as a guideline for integrating cycling into as many transport and urban planning decisions as possible. Up to the year 2010, Washington was able to implement a number of elements of the master plan. In 2010, for example, sixty miles of cycling lanes were constructed—a twenty-fold increase in comparison with 2001 (DDOT 2014). There was also a highly successful advertising campaign (goDCgo), which was addressed primarily to commuters and major employers (Sebastian 2021).

The Steady Growth of Bicycling

During the subsequent ten years, from 2010 until 2020, both cities were able to implement further cycle-friendly measures, and bicycle use continued to increase. Between 2010 and 2019, the network of cycling lanes in Washington DC was expanded by more than fifty miles. In contrast to cycling lanes of the 2000s, a portion of these new installations consisted of protected cycling routes that separated cyclists from motorized traffic (seventeen miles). These facilities are safer and more attractive for a larger proportion of the population, but they also require more space, and are hence more politically difficult to achieve (DDOT 2014). In addition, the city installed nineteen cyclist traffic lights at intersections, which compares well with the single cyclist traffic light found there in the early 2000s. Like Frankfurt, Washington began opening up one-way streets to cycle traffic in both directions (five miles). Inaugurated in 2010 was the bicycle rental system Capital Bikeshare. The system grew from 100 docking stations in 2011 to 500 in 2018, with more than 3.5 million bicycle trips annually (CaBi 2012).

In 2014, cycling was integrated into the new, comprehensive transport plan MoveDC (DDOT 2014). The cycling component of the plan is a further development of the master plan of 2005, which envisions a network of cycling routes that is denser, better interlinked, more comfortable, and safer. In 2015, Washington resolved to introduce a »Vision Zero« policy, with the ambitious goal of reducing the number of cycling and pedestrian deaths to zero by the year 2024 (DDOT 2015). In 2020, as part of the »Vision Zero« program, the general speed limit for the city was reduced to twenty miles per hour (ca. 30 km/h)—unless otherwise indicated by signage. Like Germany, Washington, DC, also introduced bicycle education into the elementary school curriculum. In the 2010s, bicycle parking was reorganized, and the integration of cycling with public transport resources improved. In 2018, 7.6 percent of all commuters traveled to work on bicycles, and 5 percent of all trips in Washington were covered on bicycles (MWCOG 2021).

By the year 2012, Frankfurt, had already achieved its goal of a bicycle modal split of 15 percent—three years earlier than originally planned (Stadt Frankfurt 2012). As in Washington, the years 2010 to 2019 saw a continuation and intensification of the promotion of cycling pursued during the 2000s. As ever, the goal was to make cycling a progressively more attractive aspect of everyday life. Introduced in 2010 was a reporting platform that has allowed Frankfurt cyclists to register more than 1,300 problems or suggestions for improvement. More than one hundred bicycle repair stations—with tire pumps and tools for use by all cyclists—were installed between 2012 and 2020. Opened in 2016 was a weatherproof parking garage at the main train station. Bicycle parking was reorganized and qualitatively improved at many other local transit stops and at other major points throughout the city—often with roofed bicycle parking spaces (Stadt Frankfurt 2016). The offering of simple bicycle parking lockups has been successfully expanded. Often, parking lockups were installed close to intersections on former auto parking places, enhancing traffic safety through improved visibility between cyclists, pedestrians, and car drivers.

After 2010, compared to the first decade of the new millennium, the bicycle has progressively come to be regarded by the majority of political parties as a crucial and useful transport resource. To be sure, the network of cycling routes in Frankfurt still displays numerous gaps, and bicycle users on designated routes must come to terms with infrastructure of uneven quality, and at times with missing connections. Overall, however, the encouragement of cycling has been highly successful. In 2018, 20 percent of all trips were covered using bicycles, and the city featured 1,400 km of cycling routes, while more than 90 percent of one-way streets have been opened to cyclists moving in both travel directions.

The year 2019 was a major turning point for bicycle users in Frankfurt. The city's three governing parties adopted a packet of measures known as »Fahrradstadt Frankfurt« (Bicycle City Frankfurt) (Stadt Frankfurt 2019). This was a response to the public petition »Radentscheid Frankfurt« (Frankfurt cycling referendum) which was signed by more than 40,000 people to pressure the municipal government to do more to promote cycling. The central component of the plan is the construction of forty-five kilometers of new, separate cycling routes by the year 2023. The protected cycling routes should be at least 2.3 meters wide, and be spatially separated from motorized traffic. In 2022, moreover, fifteen major intersections are to be redesigned in ways that take cyclists into greater consideration through infrastructural measures and traffic light signal times. The city also plans to connect express cycling routes from the outskirts directly into the city, providing direct, fast, safe cycling options. Beyond this, Frankfurt is reconfiguring up to ten kilometers of neighborhood streets annually in order to prioritize cycling traffic through bicycle priority streets and restricted access for motor vehicles. Car-restrictive measures are given explicit consideration with regard to all redesigns of roadways and intersections. At the same time, the city has appointed a working group consisting of eighteen new full-time positions in the municipal administration, charged with promoting a »Bicycle Friendly City.« In the years 2020 and 2021, an additional twenty million euros has been devoted to bicycle projects (Stadt Frankfurt 2019).

Conclusion

Despite their histories as car-friendly cities, both Frankfurt am Main and Washington, DC, have succeeded in promoting cycling, and in adapting traffic systems and traffic planning for this purpose. In both cities, the current success of cycling promotion has its roots in the early 2000s, and with similar planning approaches: both pursued objectives in a stepwise fashion. One aspect of this approach was a focus on integrating the bicycle into daily decisions concerning transportation, transport technology, and urban development. This allowed cycling planners to recognize options for implementing bicycle-friendly measures early on, and to improve conditions for cyclists step-by-step over time.

Both cities used a combination of infrastructural and other incentive measures. Regarding infrastructure, both cities introduced and qualitatively enhanced bicycle parking, installed cycling

Fig. 1 Cyclists on a cycle street on Neue Mainzer Straße in Frankfurt's city center (Source: Andreas Blitz)

Fig. 2 Cyclists on a cycle street on Pennsylvania Avenue between the Capitol and the White House in Washington, DC (Source: Ralph Buehler)

routes, including (more recently) protected ones, as well as reduced-traffic neighborhood streets where cyclists could share the roadway with small numbers of motorized vehicles traveling at reduced speeds. These measures were supported by the corresponding marketing tools, public relations efforts, and cycling training. Found among these were cycling maps, bike-to-work programs, coordination with employers, options for public participation, and bicycle training in schools. Both cities improved integration of cycling into public transport through bicycle parking places at transit stops and public transport stations; Washington also integrated bike racks in buses.

The promotion of cycle traffic mirrors the process of a change of consciousness concerning the utilization of public space and the image of the city that calls into question the absolute priority of the automobile—often with positive effects that go far beyond cycling itself. For example, bicycle parking spaces are positioned at intersections on former automobile parking spaces, thereby improving visibility axes between all roadway users and improving traffic safety. Reduced speed limits and lower levels of traffic on many streets improve traffic safety for cyclists and pedestrians alike. At the same time, noise pollution is reduced for residents. Now, urban design measures are no longer oriented primarily toward accommodating private motorized vehicles, while other aspects—including quality of life, environmental protection, and sustainability—acquire greater importance.

In contrast to Washington, Frankfurt has a longer history of implementing measures designed to make the use of private cars more expensive, slower, and less attractive. In the 1990s, for example, Frankfurt had already begun reducing car parking spaces in city center areas and introducing traffic-calmed residential districts. Washington has also begun reducing car parking spaces but started at a later point in time. Moreover, it was only in 2020 that Washington reduced its general speed limit on side streets to twenty miles per hour.

In coming years, both cities will be pursuing similar goals when it comes to expanding their network of cycling routes, in particular with protected cycling and an improvement of bicycle traffic safety, especially at intersections. Cycling has received a big boost through municipal policies designed to transform Frankfurt into a bicycle city. Additional financial resources, increased

Chart 1. Milestones in the development of bicycle traffic in Washington, DC, and Frankfurt am Main, 1990–2020

Washington, DC	**Frankfurt am Main**
1990: During the 1990s, there is no cycling planner.	1991: Establishes the position of cycling planner (the first ever in a major German city). Pedestrian zones are opened up to bicycle traffic for the first time.
1998: The regional planning organization publishes its envisioned future for cycling.	1993–1996: Part of a successful nationwide pilot project that allows cyclists in traffic-calmed residential areas to travel against the direction of motorized traffic on one-way streets.
2001: Appoints its first full-time cycling planner.	2003: Bicycle Traffic Scenario (15 percent). The plan, published in 2005, contains a bicycle-friendly scenario that envisions seeing 15 percent of all trips covered using bicycles by the year 2015.
2005: Publishes a bicycle master plan.	2009: Establishes the Cycling Office; located in the traffic department, it functions as an interface between transportation planning, transportation construction, and the implementation of transport-related measures
2014: Bicycling integrated into a new overall transport scheme “MoveDC.”	2015: Installs of electronic signs promoting cycling.
2015: Adopts a “Vision Zero” policy with the ambitious goal of reducing cycling and pedestrian deaths to zero by the year 2024.	2018: 20 percent of all trips are covered using bicycles; Frankfurt now has 1,400 km of cycling routes, and more than 90 percent of all one-way streets have been opened to bicyclists in both travel directions.
2018: The bicycle rental system Capital Bikeshare registers more than 3.5 million bicycle trips annually.	2019: The city’s trio of governing parties passes a packet of measures called “Fahrradstadt Frankfurt” (Bicycle City Frankfurt) in response to the public petition “Radentscheid Frankfurt” (Frankfurt cycling referendum), which was signed by more than 40,000 people in order to pressure the municipal government into doing more to promote cycling.
2020: Reduces its general speed limit on side streets to just 20 m/h.	2020–2021: An additional €20 million is devoted to bicycling projects in the years 2020 and 2021.

personnel, and the political will to prioritize cycling over other means of transport have the potential to make the bicycle the preferred mode of transport to an increasing degree.

In both cities, the COVID-19 pandemic generated new opportunities for more sustainable transport and for cycling. In Frankfurt, for example, the Mainkai was close to motorized traffic. During the lockdowns of 2020, bicycle use increased by 30 percent in Frankfurt, with 1150 percent more children using bicycles (Pandit et al. 2020). The experience with closing the Mainkai to car traffic contributed to strengthening plans for a shared space, and for temporary evening closures of the Mainkai to cars. During the COVID-19 crisis, neighborhood streets were closed to through traffic in Washington, DC, and many restaurants use parking spaces as outdoor seating for guests. It seems highly probable that such measures showed residents how a city with less traffic and less parked cars might look, encouraging intensive discussions of these topics in the future.

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Restorative Streets

A Conceptual Framework for Capturing—and Measuring—the Impact of Urban Streetscapes on Walkability and Mental Health

Jenny Roe and Andrew Mondschein

Jane Jacobs likened the sidewalk and street to an »intricate ballet« which »eddies back and forth with intricate vigor« (1961, 50–54) with a cast of actors and protagonists, emphasizing the street as a social experience and source of social networks. William Whyte's Street Life project (1980) continued to explore the social dynamics of cities from an anthropological perspective, documenting social behaviors in the context of urban plazas and street corners. Kevin Lynch's *The Image of the City* (1960) explored the street from the perspective of spatial cognition and »imageability,« showing how city streets and the urban fabric leave a mental image that allows users to orientate themselves in space, navigate it, and assign it meaning. Subsequently these ideas have been advanced by urban planners and designers, psychologists, sociologists, and neuroscientists, establishing streets as more than just traffic conduits; rather, they are sites for human experiences. These concepts are well-established and empirically tested but have yet to be integrated with a broader focus on active travel and walkability by transportation planners and public health specialists. Active travel, which emphasizes walking, bicycling, and other modes that engage travelers in physical activity, has remained primarily focused on physical health outcomes. Smart city initiatives, too, have sought to capture urban behavioral data but have struggled to model or diagnose mental health outcomes.

Overall, the theories of Jacobs, Whyte, and Lynch—while compelling—have not yet been brought together in a coherent framework to study how the spatial dynamics of streets affects our mental health and well-being. Particularly in a moment when health restoration is seen as integral to the planning and design of cities, we observe an opportunity to connect these long-standing theories to a multidimensional restorative urbanism framework. We therefore explore the interrelationships between urban theories in terms of what they reveal about psychological-environmental interactions, that is, how the street impacts stress, and emotional, cognitive (including neurocircuitries and brain health), and social well-being. Street life and mental well-being are interdependent in so many ways, but this web of interdependencies is far from well understood. Our approach is interdisciplinary, fusing ideas from environmental psychology, urban planning and transportation, sociology, anthropology, and neuroscience. Broadly, we contribute to a new emerging urban street science that understands streets are more than conduits for traffic, that they have significant effects on health and social processes. Given the breadth of this topic and the centrality of walking to models of psychological-environment interaction, we focus on the pedestrian experience.

In this chapter, we first review relevant theoretical models and their interrelationships through the lens of human well-being; next we synthesize the ideas within a new framework (↳Fig. 1), and then we offer a suite of methods to advance scientific enquiry and describe how a new urban street science can be put into practice (↳Fig. 2).

Existing Knowledge and Science: How Does a Streetscape Impact Mental Health and Well-Being? To date, the study of urban design and mental health has largely utilized the rubric of restorative environments from within the discipline of environmental psychology. Restoration is defined as »the process of recovering physiological, psychological and social resources that have been diminished in efforts to meet the demands of everyday life« (Hartig 2007, p.164). Researchers have examined the restorative capacity of cities from a number of perspectives, including housing and transportation, with the context of urban green space (urban parks) receiving the most attention. The bulk of the research shows busy, »grey« streets to be less restorative than »green« streets, but the evidence is not conclusive (Aspinall et al. 2015; Neale et al. 2017, 2020). Some research has shown the potential of »intriguing« street façades (and fine-grained shop fronts) for psychological restoration (Ellard 2015). Lively commercial streets may also function as restorative destinations; Barros et al. (2021) suggest that restorative attributes of streets include the social context (number of people, friends), meaningful aspects (positive memories), urban design qualities (permeability, scale), land use (variety of uses and services, coffee shops), managerial strategies (upkeep), built (benches) and natural features (trees, planting). But how each of these attributes contribute to restorative health outcomes has not been fully explored in a holistic framework accounting for a multiplicity of psychological-environmental effects, as well as their interactions.

The Rationale for a New Framework Recent decades have seen remarkable progress in the way that planners, local officials, and advocates for sustainable, equitable mobility characterize the value of transportation systems. Planners have transitioned from a mobility framework emphasizing vehicular throughput to an accessibility framework that privileges transportation's role in linking people to myriad destinations, from jobs to open space (Levinson and Krizek 2005). In parallel, the role of active travel, particularly on foot or by bicycle, has been elevated in public health and planning as a means of increasing physical well-being (Lee and Moudon 2006; Pucher et al., 2011). Walkability on local streets, therefore, has become a significant concern for planners and designers. While research has shown that the built and natural environments play a significant role in the choice to walk (Ewing and Cervero 2010; Handy et al. 2002), this research remains largely focused on the quantity of active travel (that is, the distance travelled or frequency of walking) as the critical outcome. The experiential dimensions of walking—including exposures to environmental stressors and restorative attributes, cognitive processes, and integration into social practices—remain underconceptualized and underexamined (Mondschein 2018). As a result, active travel research lacks a framework that accounts for the full spread of well-being effects of walking on the street, and walkability remains unconnected to human »whole health,« which integrates mental, social, and physical health (World Health Organization 1948). We define the positive impact of the urban streetscape on mental health and well-being as *restorative streets*.

The Potential for Restorative (or Mindful) Streets Just as transportation planners now recognize that transportation is not just throughput but a means to access a diversity of destinations, active travel research can acknowledge that the benefits of urban walking are not simply a matter of »more is better« but include a multiplicity of psychological and social dimensions with impacts on well-being. This framing resituates the street as the environment where we get our daily dose of environmental exposures and experiences that activate a range of physiological, cognitive, and affective systems. It argues that walkability is not simply a matter of ease of walking, but a qualitatively rich concept encompassing a multiplicity of effects. For the active travel community, this framework would also demonstrate the potential value of walking and quality street environments beyond simply serving as a venue for cardiovascular exercise.

An Integrated Conceptual Framework Theories of how street environments affect well-being are generally established and validated with experimental research (Mondschein and Moga 2018). Building on the work of pioneering urban design and planning scholars such as Jacobs, Lynch, and Whyte, biological and psychological scientists have identified multiple operative pathways for the effect of streets on people. What has yet to be developed is an integrated framework of human-environment relations on the street that both sets an agenda for future research and guides planners, designers, public health practitioners, and the community as they seek to improve well-being in their cities. ↳Fig. 1 sets out the constituent parts of a new framework we propose for capturing urban street science. As the figure illustrates, each theory or model addresses a portion of a broad set of human-environment interactions which take place on urban streets. Below we briefly set out each of the five constituent parts of the model and their overlaps.

Neurourbanism is a new interdisciplinary field of research focusing on the relationships between city life and mental well-being, and ultimately on the brain (Adli et al. 2017). It builds from a body of science exploring pathogenic urban stress, that is, how city living aggravates stress and serious mental health disorders such as schizophrenia (Lederbogen et al. 2011). Developments

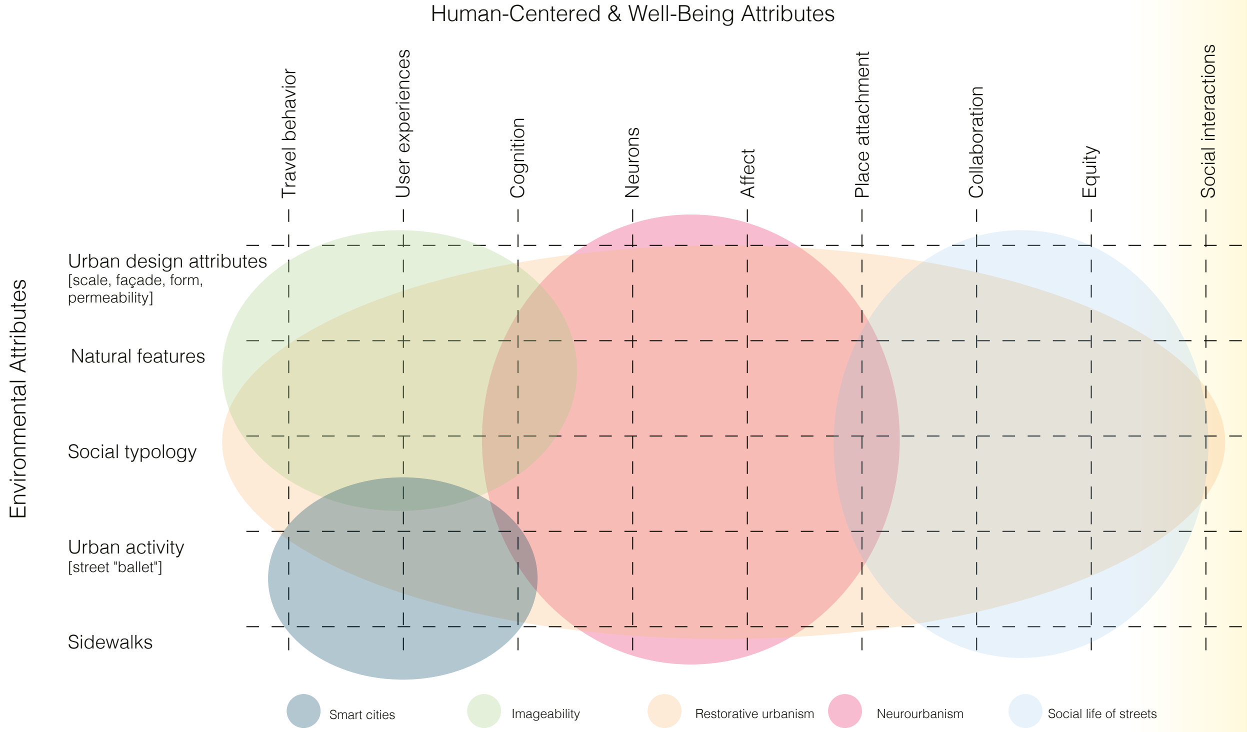

Fig. 1 An integrated framework for exploring the impact of urban streets on mental health (Source: Jenny Roe, Andrew Mondschein)

in neurourbanism are also revealing new opportunities for improved experiences in the city; for example, how the brain constructs a cognitive map and representation of the environment to support memory and help navigation. Neurourbanism also shows the advantage of experiencing nature in the city (such as street trees) in supporting alpha wave activity in the brain, linked with psychological restoration (Neale et al. 2017).

Imageability is a quality of places characterizing how inhabitants perceive their surroundings. In *The Image of the City* (1960), Kevin Lynch suggested that people form integrated mental images of their environs, encompassing urban form, routes, and opportunities. While urban designers focused on the typology of mental elements that Lynch introduced—landmarks, routes, nodes, edges, and districts—research among environmental psychologists and human geographers emphasized the idea that environments must be learned through a set of cognitive processes often called »cognitive mapping« (Golledge 1999). Subsequent research has shown that specific cells and regions within the brain are devoted specifically to cognitive mapping, with wayfinding and navigation behaviors activating those structures (Maguire et al., 2006). Further, wayfinding behavior is associated with positive mental health outcomes including the mitigation of Alzheimer's risk (Konishi and Bohbot 2013). Imageability and spatial learning are also associated with an individual's ability to function effectively in the city, including the means to access destinations including jobs, services, and open spaces (Mondschein et al. 2010).

Urban activity encompasses social relations and human copresence in urban environments. William Whyte's *The Social Life of Small Urban Spaces* (1980) catalyzed a sociological understanding of urban places, revealing that the arrangement of public spaces have a significant impact on personal comfort, behavior, and interactions with other users of shared spaces. Whyte's findings reinforced Jane Jacobs's arguments on the specificity of human-centered urban environments. Whyte and others have reinforced the idea that public places, including streets, are used by humans for a multiplicity of purposes, and that the best streets and squares enable a wide range of activities and configurations (Gehl 2013). Subsequent researchers have emphasized the social and political dimensions of streets, identifying streets and sidewalks as critical venues for encounter and confrontation (Loukaitou-Sideris et al. 2005). As social movements combating structural racism and political repression have manifested, the importance of streets both as sites of oppression and of political expression and protest has only been reinforced (Sheller 2018).

Smart cities embraces the idea that urban processes can be made more efficient, sustainable, and even equitable with the application of technology and optimization (Yates 2017). In smart cities, sensors, analytics, and automation can all be applied to monitor conditions and adjust infrastructure and behavior. With their reliance on digital systems, smart cities depend on a »quantified urban science« based on systems thinking and copious amounts of data (Bettencourt 2014). As such, smart cities popularize a quantified-city/quantified-self ethos that includes tracking of human behavior, measurement of environmental conditions, and integration of previously separate data streams in ways that could provide new insight toward well-being in cities. However, the actual science of smart cities remains significantly underdeveloped, particularly with regards to human well-being. Smart mobility systems remain focused on traffic optimization with little attention given to the multidimensional health effects of street behaviors.

Restorative urbanism is a new approach that puts mental health, wellness, and quality of life at the forefront of city planning and urban design (Roe and McCay 2021). It builds from the principles of restorative environments research and thousands of scientific studies showing how urban design can support mental health. It also has the capacity to integrate a theoretical framework connecting/overlaying some of the theories above. For example, the signatures of restorative urbanism include well-connected cities and legible wayfinding systems (resonating with the ideas of Kevin Lynch); high-quality aesthetics in urban form; dynamic, multifunctioning neighborhoods that support people's everyday activities; and the existence of nature right into the city core (biophilic urbanism). The model also assigns importance to the smaller signatures of city life—the psychological experience of episodic street interactions (interactions with market street sellers and food stalls, for example)—building off the urban heritage of Jane Jacobs and William Whyte.

Toward an Integrated Framework Many of the theories in our framework overlap but have not been integrated in a holistic urban street science framework. How they overlap in relation to well-being and to the physical streetscape is captured in ↳Fig. 1. The imageability and social dimensions of streets, for example, are inherently connected, with positive (or negative) social experiences becoming significant features of an individual's mental map. Conversely, a socially determined sense of belonging on the street is critical for positive affective outcomes while walking. Restorative urbanism and neurourbanism are both driven by human-centric interests and an understanding of what qualities of the urban fabric city can improve the experience of the city and well-being. Lynch's theory of imageability and the idea of coherent and legible navigation in the city reduces confusion and supports mental well-being. Smart cities open up the possibility of integrated modeling of street environments and behaviors, but the integrated conceptual framework has not yet been developed. Broadly, each of these theories interacts with the other, and we hypothesize that the most positively restorative street environments must account for all dimensions of the walking experience.

Operationalizing the Framework

A holistic framework for capturing restorative streets as proposed above requires a robust methodological framework that can allow it to be tested and operationalized. ↳Fig. 2 sets out a mixed-methods framework designed to capture the complexity of the self: (1) the »quantified self«—the self in data and numbers—using science-informed technologies to capture, for example, metrics of body physiology; and (2) the »unconscious self,« our perceptions and feelings that remain largely unseen and which are more difficult to capture. For many psychologists (and philosophers) our human understanding of the environment is based entirely on our internal interpretations rather than on any concrete, real world attributes. In ↳Fig. 2 and below, we suggest methods that can capture the inner representations of our world (using qualitative methods) and the physiological, objective world of body and brain mechanics using hard science.

Mapping Behavior The health outcomes of street behaviors are often dependent on spatial dimensions such as proximity (to a tree or to pollution), distance, or speed traveled. Mapping behavior, as well as perceptions of the environment, are essential to understanding the effects of street environments. Behavioral mapping has made significant strides in recent decades, in large part due to the advent of GPS-based tracking. Numerous wearable devices, including smartphones, have GPS tracking capability that can precisely and continuously measure walking and other behaviors. Additional sensors, such as accelerometers built into phones, can more accurately measure speeds, stumbles, and other features of human mobility. These tracks can readily be included in Geographic Information Systems (GIS) that allow the overlay of other measures, described below, which can be tied to location and behaviors in space and time. Emergent techniques for mapping behavior include crowdsourcing data from social and geosocial media platforms, including Twitter, Facebook, and Yelp, which is being used, for example, to understand visitation patterns to urban parks and streets. The proliferation of mobile phones has enabled widespread collection of high spatial and temporal resolution data for use in urban mobility research (Lenormand and Ramasco 2016).

Mapping Perceptions Subjective perceptions of the experience of place can now be combined with GPS via smartphone apps that help capture our inner interpretations and experiences of our world on the move using techniques such as experience sampling methodology (ESM). Social media data (such as from Twitter) is a potential new research method to capture experiential narratives that are also geolocated. Other tools include behavioral mapping that uses observational methods to map how people use and interact with city spaces, drawing also on the idea of affordances (that is, »what's in a place for me«) that can capture the physical, social, and emotional affordances offered by the physical world. Information extracted from cognitive maps can also be integrated into the same system. While open-ended sketch maps—like those used by Lynch—that prompt individuals to draw their perceptions of routes, landmarks, and other features of the built environment still have value, digital mapping allows individuals to share their perceptions of positive and negative experiences, critical locations, and local features directly into GIS (Miller and Goodchild 2015). Geographers and planners have developed software and hardware tools to facilitate the contribution of cognitive map elements.

Neuroscience Techniques Wireless technology is advancing a new paradigm in neuroscience research, including mobile neural head sensors free of wires and cables that can capture brain wave activity as people move freely through their environment. Smart watches can capture stress biometrics (such as heart rate, heart rate variability, and galvanic skin conductance) in real time, and eye-trackers inform understanding of our visual engagement with urban streets as well as capturing affective and cognitive responses to the built environment through eye blink and pupil diameter (Hollander et al. 2019; Simpson et al. 2019).

Mapping the Environment Paralleling advances in the measurement of human factors are new approaches to measuring ambient environmental conditions in streets and public spaces. In the past, urban researchers had to rely on spotty, stationary measures of environmental conditions often extrapolated to whole sections of cities. Mobile and wearable sensing technologies have enabled

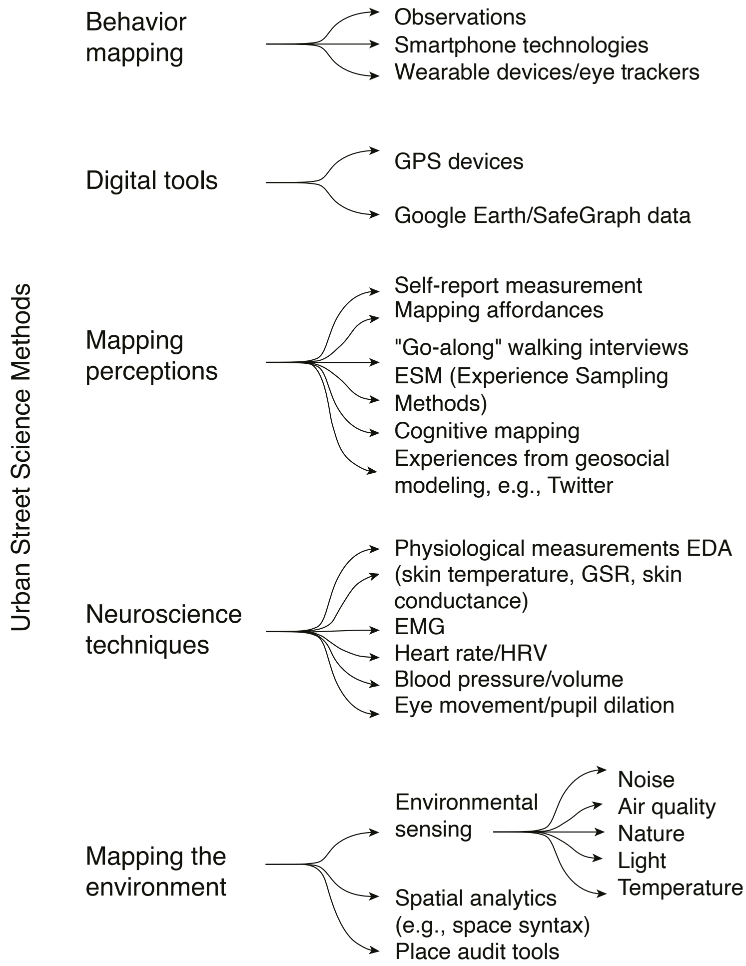

Fig. 2 A mixed-methods framework for evaluating the impact of urban streets on mental health (Source: Jenny Roe, Andrew Mondschein)

researchers and communities to assemble more spatially and temporally precise data on local environmental conditions at significantly lower costs than what was possible previously (Gabrys 2014). Key environmental features including noise, air quality, temperature, and light levels can be measured using sensors carried by pedestrians and often integrated with technology already on smartphones (Roe et al. 2020). These environmental factors are associated with traffic levels, built and natural features, and other planning and design choices that constitute street environments. Mobile and wearable sensing data, tied to GPS, can then be integrated with the other human-centered measures already described.

Space syntax is a tool that can quantify and characterize the spatial properties of buildings and streets (Hillier 1998; Hillier and Hanson 1984), allowing the street to be considered at a human scale as opposed to at area-level units (such as census block in the US) or as an activity space captured by GPS (global positioning systems). Space syntax captures four characteristics of the built environment: (1) building density (the percentage of land cover), (2) street integration (that is, how easily one can access a given street from any other in a street network), (3) visibility (using isovists to capture the volume of space visible from any single point in space), and (4) open space typology (for example, a park, courtyard, street). These spatial and visual aspects of urban form can then be correlated to well-being outcomes. Knöll et al. (2018) used space syntax to understand the psychological experience of a city, showing that certain open space typologies (park, square, courtyard, streets) are the best predictors of perceived urban stress. Survey tools that capture architectural scale and complexity together with the dynamics of street life (Bloomberg et al. 2013; Gehl and Svarre 2013) can also provide a rich source of data to correlate with well-being metrics.

Summary: The Potential of the Methods to Advance Science and Understanding By integrating these methods, new conceptualizations and measures of walkability become possible. Rather than focusing singly on behavior, physiology, affect, or cognition and knowledge, these methods contribute to a layered understanding of human experience of walking on the street. By integrating human factors with environmental data from sensors and high-resolution mapping, new relationships between (a) design and planning, (b) environmental conditions, and (c) human health can become apparent. For example, differences in the restorative effects of urban nature that are due to cognitive or social variations across populations can only be identified, understood, and addressed when the concepts and tools we describe here are brought together. Similarly, the intersecting effects of physiological stressors such as pollution and sociocultural effects of unjust traffic enforcement require conceptual breadth and methodological integration to adequately address well-being. Challenges remain in synchronizing complex geodata sets, mind-body data, and environmental data in real time. These data require new statistical approaches capable of handling integrated time-space modeling, working across geographic scales, and errors arising from user behavior, sensor limitations, and sampling methods.

Discussion

Above we offer a comprehensive framework for conceptualizing (and measuring) how mental health outcomes are associated with daily mobility in urban streets. We have drawn on a wealth of conceptual frames and disciplinary perspectives, each of which characterizes something about the psychosocioculture of the street and its effects on well-being. To date, conceptualizations of well-being have been mostly latent (certainly in Whyte, Lynch and Jacobs) and limited in urban planning and design. Restorative urbanism and neuro-urbanism do place well-being at the forefront, but they have not been thought of as a multilayered model (↳Fig. 1).

This is an opportune time to capitalize on a comprehensive model of street mobility and well-being. First, the advent of new methods and rise of smart cities offer a key venue for capturing the metricated city (and quantified self) but currently this is driven by utilitarian agendas (to make cities more efficient) and lacks a human focus. The smart cities paradigm has been criticized for failing to engage communities in metrification; integrating a focus on resident well-being can provide a new template for generating both more efficient and stronger local communities.

Second, COVID-19 has increased the importance of urban streets for well-being and changed how we live, work, and socialize. During the pandemic, we spent more time on our local streets; they were where we shopped, communicated with one another, and exercised under social distancing restrictions. COVID-19 has also kick-started a new trend toward localization and increased demand for safe, comfortable streets where we can enjoy a range of activities other than retail. Paris, for example, is prioritizing the beautification of its streets and integrating new functions (play streets, for example). Having a comprehensive framework by which to capture and measure such change is important in scaling up such efforts to other contexts.

Finally, mobility justice has become a priority for cities and transportation practitioners, and a full accounting of the ways in which daily travel impacts well-being is essential (The Untokening 2017). Intersecting experiences of environmental pollution, social segregation and oppression, and barriers to accessibility may come together to create significant psychological and health effects. A holistic model of health impacts of walking and other modes of travel will be critical if we are to effectively identify and address the layers of planning, engineering, design, and enforcement that have historically resulted in unjust and inequitable outcomes for many communities.

Conclusion

We seek to empower planners, designers, public health specialists, and communities themselves to create streets that don't simply facilitate access to a destination but facilitate human health across multiple dimensions. Recognizing the breadth of the human experience of daily mobility is an opportunity for designers and planners to realize Jacobs's intricate ballet of the street. In so doing, we have an opportunity to move beyond connectivity as the sole purpose of transport infrastructure and instead acknowledge the role of walking and other forms of mobility as moments of potential restoration during our daily activities. This project requires interdisciplinary thinking that incorporates neuroscience, environmental psychology, transportation, urban planning, sociology, and other disciplines that observe interactions between travel, environments, and well-being. Further investigation of these relationships is paramount for a new urban science of the street.

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Cycle Streets

Encouraging Cycling through Design

Janina Albrecht, Andreas Blitz, and Peter Eckart

The installation of cycle streets—streets where cycle traffic takes precedence over motorized traffic—can be understood as cycling marketing translated into infrastructure: [01] bicycle traffic from the surrounding streets is bundled in such a way that the increased ratio on a cycle street results in a sense of heightened security, while also increasing real security through enhanced visibility. The repurposing of cycle streets also generates increased attention to the topic of cycling within a given municipality. But the concept of the cycle street also makes it possible to completely reconceive the street space from one façade to the other, with the aim of creating an inclusive infrastructure that gives due consideration to everyone who moves along the street, spends time there, or lives there. The dominance of the automobile is opposed by a concept that integrates all users and reanimates the street as a public space. In practice, however, this potential impact is often weakened by the fact that many cycle streets are open to automobiles, which might result in high levels of motorized traffic traveling at excessive velocities. Oftentimes, unfamiliar or ambiguous markings and signage represents a challenge as well. Can mobility design make a fundamental difference by using design decisions to mediate between users and the mobility system while positively influencing user experience and user decision-making?

For a number of years now, Offenbach am Main has been working to expand its network of cycling routes, and in 2018, the city launched the project »Bike Offenbach« with the aim of creating six cycle streets for a total length of nine kilometers (see Stadt Offenbach am Main 2018). In city-center zones with higher structural density in particular, the reconfiguration of the street space is designed to reduce car traffic, leading to an enhanced amenity quality. On these cycle streets, comprehensive design measures with high recognition value are intended to ensure adequate visibility. Certainly, the »Guidelines for Bicycle Traffic Infrastructure« issued by the German Road and Transportation Research Association recommend such a structural clarification of the function of cycle streets but contain no precise Germany-wide design requirements (see Becker 2019; FGSV 2010). This increases the usual leeway when it comes to municipal traffic planning, a circumstance illustrated by the diversity of designs for cycle streets in various German cities and communities (see Graf 2018).[02] At the same time, the absence of clear guidelines can lead to the use of ambiguous markings. This became clear when a 500-meter-long test route was laid out on Senefelderstraße in Offenbach. In response to persistent public discussions and misunderstandings with regard to utilization, the »Bike Offenbach« project management decided to call on the specialist competency of designers at the University of Art and Design Offenbach (HfG). This approach meant an opportunity to analyze the test route from a design perspective, while developing new concepts and deploying these findings directly in practice. Central concerns were the creation of intuitively comprehensible markings and factors designed to enhance the amenity quality. At the same time, social scientists from the Goethe University in Frankfurt conducted a comprehensive written household survey around Senefelderstraße (n=701) and interviews with residents to investigate empirically levels of acceptance of the cycle street and its public perception as well as to discover which role mobility design could play in promoting nonmotorized mobility. Designers and social scientists engaged in an intensive exchange of ideas,[03] as well as with the relevant protagonists of Bike Offenbach, which included the project management (»Offenbacher Projektentwicklungsgesellschaft«), the office for city planning, the transportation authority, and the bicycle planning agency

01 This text is based in large part on the extensive documentation compiled under the title »Design- und Forschungsprojekt Fahrradstraßen: Mobilitätsdesign im Kontext von Verkehrswende, Aufenthaltsqualität und Intermodalität am Beispiel Offenbach am Main,« authored by Janina Albrecht and Peter Eckart, 2020 (https://project-mo.de/de/portfolio-item/fahrradstrasse-offenbach/).

02 As with other municipal roads, the respective municipality is responsible for installing cycle streets (Kregel 1983).

Fig. 1 Cyclists riding on safety demarcation lines of the test route, instead of in bike lane (Source: Janina Albrecht)

»Radverkehr-Konzept.« Foregrounded in the following account are design aspects in particular (for detailed information about the social scientific research, see Baumgartner et al. 2020; Blitz 2020; Blitz et al. 2020; Blitz et al. in this volume).

The Baseline Situation: Analysis of the Test Route

The local characteristics of the test route were first analyzed: the allocation of traffic space, traffic volumes, parking zones, intersections, visibility at crossings, green spaces and roadside trees, access to shops and residences, as well as routes and the requirements of the various user groups (see Albrecht and Eckart 2020: 13–27). Central here were the perspectives and the safety of cyclists. The following aspects were given special preeminence: the marking of safety dividers, markings at crossing zones, unobstructed view axes as well as surface allocation and traffic volume.

The double broken lines on both sides of the roadway are meant to serve as safety demarcation lines and lane markers on the cycle street. They indicate the minimum distance between cycle lanes and parked cars and are intended to prevent accidents caused by car doors that open suddenly and by inadequate distances between bicycles and stationary vehicles (»door zone«). In the beginning, these lines were frequently misinterpreted as designating bicycle lanes, and cyclists rode in the door zone rather than in the actual cycling lane—the reverse of the intended effect (see Kuhn 2018; Baumgartner et al. 2020: 19–20; ↳Fig. 1).

At crossings, the traffic lane of the cycle street was colored red, with a white dotted line alongside the red surface to additionally highlight the crossing roadway. A lack of stop lines on the intersecting streets, however, meant that road users at crossings drove right up to the dotted crossing line. This made it difficult for cyclists to tell whether their right-of-way was being respected, diminishing a sense of safety. The numerous staggered and variegated markings seemed unsettled and were not intuitively legible (see Albrecht and Eckart 2020: 18; ↳Fig. 2).

The start of the cycle street was also marked by a red area. This occupied the entire breadth of the roadway. Given its extension, cyclists were often forced over toward the side of the road (↳Fig. 3).

This conversion to a cycle street entailed only minimal alterations to the roadway and to the allocation of surface areas for the respective modes

Fig. 2 Markings at a crossing area along the test route (Source: Janina Albrecht)

of transport, although from that point onward, only neighborhood residents were permitted to drive cars on that street. Speed measurements showed that the majority of automobile drivers exceeded the thirty-kilometers-per-hour limit by a considerable degree (see Büttner 2019). Excessive speed, the large share of other traffic, and the car parking areas all underscored the disequilibrium that prevailed on the cycle street. Bicycle use was also discouraged by the perceived and actual risk of being hit by opening car doors, the failure of cars to observe right-of-way, and the experience of close calls when cars passed cyclists (on perceptions of the test route, see also Baumgartner et al. 2020: 15–19).

The Development of Intuitively Intelligible Roadway Markings

How, then, can the roadway be configured in such a way that the various user groups intuitively understand street markings, particularly when there exists no tried-and-tested, unified standards for cycle streets? In order to develop concepts for the Offenbach cycle streets, international best practice examples and scientific studies were examined alongside the analysis of the test route. These demonstrated how markings can be used in order to support traffic infrastructure and the observance of traffic regulations. Straight lane markings and median strips have an accelerating effect, while wavy or zigzag longitudinal markings can draw attention to hazards, encouraging deceleration. Lane lines can also aid orientation or serve other functions. An important role is played as well by pictograms: they permit intuitive recognizability, quickly conveying traffic signs and hazards. Site-specific designs can add to the graphic enhancement of cycling infrastructure.

Along the Offenbach test route, the erroneous interpretation of the marked door zones as designated bicycle lanes made it clear that no learned semantics were available to indicate their

03 This collaboration between designers and social scientists took place under the context of the research project »Infrastruktur–Design–Gesellschaft,« which was funded between 2018 and 2021 by the Landes-Offensive zur Entwicklung Wissenschaftlich-ökonomischer Exzellenz (LOEWE) in the German Federal State of Hesse. The project partners were the HfG Offenbach University of Art and Design (design, consortium management), the Frankfurt University of Applied Sciences (transportation planning), the Goethe-University Frankfurt (social sciences mobility research), and the Technical University of Darmstadt (multimedia communications; architecture/urban design).

Fig. 3 Markings at the beginning and end of the test route (Source: Janina Albrecht)

function as a passive surface that needed to be free of travelers. On the contrary, cyclists are all too habituated to being pushed toward the edge of the roadway, and hence toward parked cars, by excessively narrow safety dividers. For this reason, the marking should convey the function of a demarcated door zone intuitively while pointing to the area that should be used. A number of design variants were developed and discussed with the involved parties of Bike Offenbach, among them diagonal hatching lines and fanned lines (↳Fig. 4). The hatching lines run diagonally and follow the semantics of a keep out area, reinforced by their orientation in opposition to the travel direction (always on the right-hand side of the roadway). With the fanned-out variant, the markings, which visually refer to the arc of an opened car door, begin from the parked car and are oriented against the cyclist's direction of travel. With both variants, the haptic and acoustic effect of the markings also called attention to their function as safety lines when they are ridden on in error (unlike markings involving lines running parallel to the roadway). Both variants were included in the household survey, along with the existing design of the demarcated door zone on the test route.

The survey results showed that the majority of people favored the hatched lines, which were deemed the most appealing markings, as well as the most intelligible. Moreover, they appeared to be the most feasible solution for Bike Offenbach.

With the new concept (concept NOW), just as along the original test route, surface markings at all intersections along the cycle street were intended to call attention to the altered traffic environment. The household survey presented a selection of the colors red, green, and blue. The results showed that a large majority of participants perceived the red markings as being far more recognizable than the other options, so this color was deemed advisable for subsequent implementation. Unlike the original test route, the new concept envisioned red markings only for areas where bicycles were actually meant to be ridden. An interval of separation from the curb having the width of a door zone produces a buffer zone (protected space) along the roadside. Additionally, the red surfaces at the start of the cycle street are extended further into the roadway, creating a tapered shape that is designed to contribute to the deceleration of traffic. Because an even ending of the red marking acts as the end of a stretch several designs were

Fig. 4 Design variants for the demarcated door zone: the double dotted lines of the test route, diagonal hatching lines, and fanned-out lines (Source: Janina Albrecht; see Albrecht and Eckart 2020: p. 47)

considered (including hatchings, waves, zigzags) to convey its meaning to the unmarked surface. Finally, a diagonal transitional shape was selected, as it was seen to embody dynamism while calling attention to the right-hand side of the roadway, hence having a decelerating effect. The slanting lines are highly conspicuous, yet their straightforward formal arrangement avoids creating a distraction from what is happening on the road (see Albrecht and Eckart 2020: 44; ↳Fig. 5).

Furthermore, in the course of the road a bicycle symbol is painted within a white rectangle and the text stating »cycle street« to indicate the street's special status (Zeichen 244 (StVO)).

Improvement of Usability and Amenity Quality through the Design of the Streetscape as a Whole

Research into examples of best practices along with numerous studies have identified the factors that make a transportation infrastructure for bicycles more appealing: a reallocation of road space, use of materials, forms of traffic calming, bodies of water and green areas, markings, informative guidance systems and recognizable icons, attractive illumination, and routes with sound effects while cycling along can all give rise to a safe infrastructure with high experiential quality. Indispensable, moreover, is the spatial integration of cycle streets into the surroundings, ensuring intuitive utilization.

With a point of departure in these research results and the test route in its above-described form, designers at the HfG developed three concepts for cycle streets. They focus on the routes and needs of nonmotorized road users, and take into account aspects like safety, acceptance, amenity quality, convenience, and consistency as well as social value and integration into the urban fabric (see Albrecht and Eckart 2020: 42f.; Vöckler and Eckart in this publication). While concept NOW, presented in the preceding section, uses a variety of roadway markings that intervene only minimally in the prior street structure and can be implemented in the short term, the FLOW and SHARED concepts (↳Fig. 6) go somewhat further.

FLOW is based on a familiar subdivision—dedicated zones for pedestrian traffic, parking, and moving traffic—but it alters the street layout, using curved lane markings, islands and crossing aides, green areas, and special offers for cyclists such as repair stations. Functional densification decelerates traffic and encourages an intuitive and diversified utilization of the street that respects the needs of pedestrians and residents. SHARED, in turn, pursues the idea of a fundamental reconfiguration, and abandons the concept of an express cycling lane. The focus is on amenity quality and inclusion and is based on research into the routes of various traffic participants that was performed at the start of the analysis. SHARED dissolves the boundaries between sidewalk and roadway, emphasizing the breadth of the street from one façade to the other (rather than the customary division of the surface area parallel to the direction of traffic flow). This promotes relaxed, comfortable cycling, offers more space for pedestrians, and invites people to relax and linger on benches

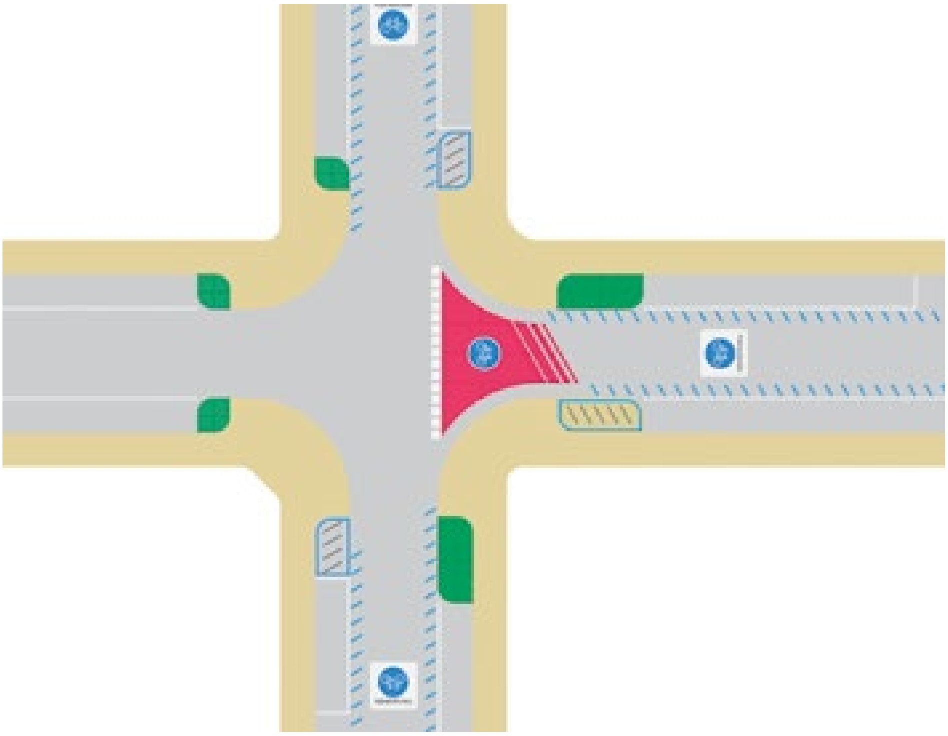

Fig. 5 New concept for demarcating the beginning and end of the cycle street (Source: Janina Albrecht; see Albrecht and Eckart 2020: p. 51, fig. 83)

and green areas. A precondition for the success of this concept is deceleration and a substantial reduction of car traffic (for a detailed presentation of this concept, see Albrecht and Eckart 2020: 52–73).

Together with the original design of the test route, FLOW and SHARED were included in the household survey and interviews with residents that were conducted by social scientists at the Goethe University in Frankfurt. The visualizations made the various conceptual approaches comprehensible, facilitating user anticipations of new forms of mobility. In the interviews, the FLOW concept, with its structural modifications, together with the retention for the most part of the existing space allocation, met with the highest approval from the perspective of bicycle users, since this model ensures the maintenance of rapid cycling (see Baumgartner et al: 24–26). The results of the household survey indicated that—independent of the prioritized mode of transport—both FLOW and SHARED were seen to more likely contribute to the beautification of the cityscape and to safety and a sense of well-being than the test route.

Conclusion

Cycle streets are an effective means for promoting bicycle use and cycling safety but require a design that clearly displays the existing regulations while reducing potential danger to the greatest possible degree. The versions of elements such as the markings of door zones and crossing areas, and bicycle symbols developed in the research project took account of both intuitive associations and efficient implementation in appropriation to the material. Together, they represent a model solution that is to be used for all cycle streets planned in Offenbach (↳Figs. 7+8).[04] It has become evident, for example, that the modified markings for the door zone have actually enhanced an intuitive understanding of its function. At the same time, a ride taken with a focus group revealed that the color blue preferred by the city of Offenbach for the strips was to some extent perceived as lacking in contrast, and hence more difficult to see in lower light conditions (on this group ride and the use of focus groups, see Schäfer et al. in this volume). In accordance with international guidelines, moreover, blue markings are earmarked for parking spaces with certain restrictions (see UNECE 2006).

Fig. 6 The FLOW and SHARED concepts for cycle streets (Source: Janina Albrecht; see Albrecht and Eckart 2020: pp. 58 and 72, figs. 102 and 130)

On cycle streets in German cities and municipalities, meanwhile, the absence of uniform standards represents an impediment to the unambiguous identification of markings. The approaches described here, however, suggest the potential for shaping and improving the usability and amenity quality of streets through intuitive markings, and beyond this, of the overall design of the streetscape. In order to transfer this accumulated knowledge and experience to other contexts, thereby contributing to the implementation of readily identifiable, well-functioning, appealing cycle streets in other communities, it would seem useful to formulate a set of universal design guidelines for cycle streets on the basis of the above approaches, while conducting additional research into the effects of various models. The expertise of specialists in mobility design should be integrated into this process. Required, ultimately, is the political will to oppose purely car-oriented planning and to instead devote greater surface area to cycling and pedestrians, even if this necessitates unpopular decisions such as the reduction of car parking spaces. In the absence of an equitable allocation of space, an implemented cycle street may be perceived by cyclists as a superficial public relations maneuver and may be regarded—as a result of heightened attention in the press and social media—far more critically than other streets. Close collaboration between planners, designers, and politicians with regard to implementation, as well as the inclusion of the citizenry, may nonetheless lead to positive results and a greater degree of acceptance.

04 Because parking places were not eliminated during the installation of the cycle streets, the roadway in some places was so narrow that the blue diagonal lines marking out the door zone have been applied only on one side of the street, substantially reducing safety.

Figs. 7+8 The new markings are installed, Taunusstraße Offenbach, May 2020 (Source: Julian Schwarze, Kai Vöckler)

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Practice-Led Design Research (III)

Reconfiguring Bicycle Mobility and Integrating It into the Transport System

Anna-Lena Moeckl, Julian Schwarze, and Peter Eckart

From the perspective of sustainability, environmental protection, and health, cycling is a form of active mobility that outranks motorized personal transport (BMVI 2021: 11). In urban areas in particular, the advantages of cycling are immediately evident: space requirements, for example, are far lower, while cycling produces virtually no noise and has practically no environmental impact (regarding the space requirements of the various modes of transport in moving traffic per person, see Randelhoff 2014). But how can bicycle mobility be promoted using new design concepts? How are new incentives encouraging bicycle mobility to be generated? A systematic approach that regards the bicycle not merely as a product, but instead as an element within a larger intermodal (and environmentally friendly) mobility system is essential. From the user's perspective, moreover, the bicycle should be considered as a mode of mobility in conjunction with transport infrastructure that is operated by other mobility providers.

Promoting Bicycle Mobility

Bicycle design addresses all variants of this mode of transport, including cargo bikes, recumbent bicycles, and children's bicycles, but also accessories, including trailers for children or cargo, transport baskets or bags, locking devices, along with ergonomic attachments. Here, the selection and combination of elements is determined primarily by the requirements of the individual user as they relate to the specific (mobility) situation. The bicycle infrastructure, in turn, facilitates movement and orientation for cyclists while guiding traffic flows. A systemically designed bicycle infrastructure incorporates aspects of road safety, for example, specially installed cycle lanes that provide separation from both car traffic and pedestrians. But it also integrates aspects of comfort and serviceability, such as footrests at stopping places and service stations with bicycle pumps, which provide infrastructural support to bicycle mobility in ways that resemble service stations for automobiles. Similarly, the creation of access points and transitions to and within the overall transport system via bridges or elevated bike lanes may form parts of a (new) bicycle infrastructure in ways that facilitate new forms of use of the mobility system. Safe parking facilities for cyclists, in bicycle parking garages, on cycle racks, or at specially secured locking stations make demands on the planning, design, and implementation of a well-equipped infrastructure that is oriented toward the user's needs. With the bicycle infrastructure, differently than with the bicycle itself, it is less the individual's needs that stand in the foreground; given primary consideration instead are the collective needs of all bicycle users. The interests of society as a whole too must be taken into account if the relevance of structural changes to the respective mobility element is to be evaluated and shaped accordingly.

But how can people be motivated to regard bicycle mobility not solely as a leisure activity, instead integrating cycling into everyday mobility as a self-evident element? How can design contribute to enhancing acceptance of bicycle transport as a sustainable, cost-effective, environmentally friendly, and efficient form of mobility that is used on a regular basis? Design and design research strive to develop new, innovative mobility concepts or optimize existing ones and conveying their findings to current or future users of the mobility system. Design measures make it possible not only to arrive at solutions to existing problems, but also to generate possibilities for reconceiving bicycle transport, in terms of both the bicycle as a product and the cycling system as a whole. In order to raise awareness of the functionality and attractiveness of cycling, design incorporates these factors into product development, linking individual and social needs conceptually. Design therefore takes into account individual needs as they relate to the bicycle as an object, but also conceive of these needs as an aspect of an overarching, intermodal mobility system. The questions raised above will now be explored and illustrated through three projects.

The Reconfiguration of the Bicycle as a Product

How can loads be transported conveniently and comfortably using bicycles? In cities, combining travel via bicycle with the transport of loads or large purchases is generally achieved only with

Figs. 1+2 Through a simple motion, the bicycle becomes a cargo bike. (Source: David Maurer-Laube/Convercycle)

a special cargo bike, and hence confronts many cyclists with difficulties. Also, a cargo bike is not particularly practicable when no loads are to be transported. They are unwieldy, require considerable parking space, and cannot simply be carried onto suburban trains, for example. The »Convercycle« (design: David Maurer-Laube) addresses this problem head on.[01] It combines comfort, experiential quality, and function, and encourages people to use the bicycle more frequently, even when transporting loads. By reconfiguring the bicycle based on user needs, it generates a new mobility option: the two-wheeler is an ordinary bicycle and a cargo bike at the same time. Depending upon which type of bike is required, it is adaptable to everyday needs through a clever folding mechanism that is operated by means of a handle on the rear wheel (↳Figs. 1+2). The bike unites the advantages of a short, easily storable, lightweight, maneuverable city bike with the transport options of a cargo bike that accommodates purchases, sports bags, beverage crates, or baby seats. The success of this reconfigured bicycle is clearly evident: David Maurer-Laube has been pursuing development, marketing, production, and sales through his own extracurricular startup, and has already sold more than a thousand units since 2019, with sales now averaging around fifty monthly.[02]

How can active mobility become a sustainable and individual experience? Another possibility for reconceiving the bicycle and better adapting it to individual needs is through ergonomic optimization, so that each bicycle becomes distinctive and personal while at the same time optimizing the mobility experience. This becomes possible through the digitally supported data capturing of the bodily dimensions of the individual user and the corresponding adaptation of the bicycle frame through the insertion of individually manufactured frame parts through 3D printing. Through this concept, »Frame One« offers a customized bicycle (design: Felix Pape and Mervyn Bienek).[03] To begin with, the dimensions of the projected customized bicycle are determined by measuring the user and taking into account his or her personal riding habits. An individualized frame that conforms to the individual's physical needs is created on the basis of a frame algorithm. Finally, the frame is manufactured locally on-site using 3-D printed sleeves and readily available, cost-effective, semi-finished products, and outfitted with the appropriate accessories. The personalization of the bicycle not only allows functional and aesthetic adaptations, but also reduces health problems by significantly improving cycling posture (↳Figs. 3+4). The bicycle's design and the manufacturing process facilitate a local, intelligent, cost-effective production approach that counters the pull of mass production. Felix Pape and Mervyn Bienek are developing and marketing »Frame One« through an independent, extracurricular startup, and have already realized a functional prototype.

The Adaptation of Bicycle Infrastructure to the Experience of Mobility

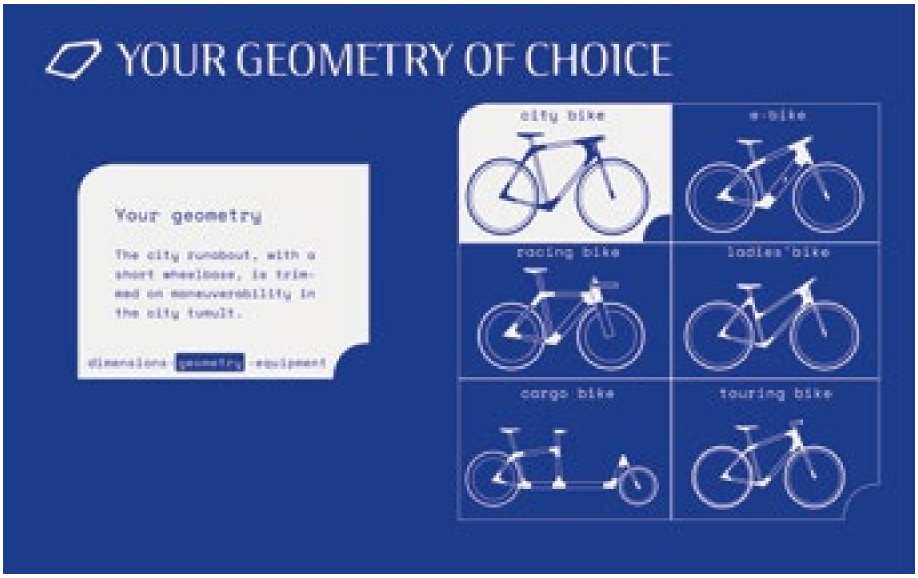
As a rule, transport infrastructures are planned from a purely functional perspective: how can people or goods be transported from point A to point B with maximum efficiency? This seems reasonable enough, but that approach often neglects the user's needs, resulting in a less satisfactory mobility experience. In the end, the experiential quality and comfort of the mobility experience call for something more than a seamless, functionally conceived process. It is at this point that design comes into play: how can a networked transport infrastructure—in this case for bicycle traffic—be adapted to individual needs? How can the larger social significance of an environmentally friendly mode of mobility be communicated, with the aim of promoting identification with and acceptance of it?

One example is the design project »Green Line« (design: Andreas Grzesiek), which emerged from a student ideas competition organized by the Regionalverband Rhein-Main and the Fraport AG, and which expands the existing transport infrastructure at Frankfurt Airport's Terminal 2 to include a bicycle bridge.[04] As the region's largest employer, the airport represents considerable potential for influencing the mobility habits of its employees in a positive way through special options. Moreover, the adjacent municipal forest, with its bike routes in green surroundings, encourages active mobility as a link between the airport and downtown Frankfurt or with neighboring residential areas. Up to now, the transport infrastructure at the airport itself, however, was almost

01 The »Convercycle« originated in the winter semester 2017–2018 at HfG Offenbach University of Art and Design, which was devoted to the topic »The Bicycle in the City,« in the course »wheel2wheel« (supervisors: Peter Eckart with Anna-Lena Moeckl and Julian Schwarze).

02 According to Convercycle Bikes GmbH, these numbers reflect sales as of January 2022 since market launch in June 2021 and from an earlier Indiegogo campaign.

03 »Frame One« emerged in the University of Art and Design (HfG) Offenbach summer semester of 2016, which addressed the topic »The Bicycle and Urban Production,« in the course »bike.0« (supervisors: Peter Eckart with Julian Schwarze).



Figs. 3+4 Configuration and finished customized bicycle with individual connecting elements (source: Felix Pape, Mervyn Bienek/Frame One)

hostile to bicycles, especially at an intersection and feeder road that were to be integrated into the network of cycle routes around the airport by the ideas competition. The design was developed from the perspective of bicyclists: to a great extent, the cycling route leads through the municipal forest, and is confronted with a challenging traffic situation only in the area of the crossing. The design, which takes the form of a forest aisle, cites the airport's wooded surroundings, continuing the positive experience of nature through the intertwining of landscape and bridge elements. The resultant wave form offers cyclists view and noise protection while serving as an icon of environmentally friendly mobility (↳Fig. 5). The design offers a positive mobility experience, generates visibility for this mode of transport, while at the same time achieving a powerful symbolic impact.

The projects presented here demonstrate how design can promote active mobility and encourage people to switch from other forms of mobility. First, there is the design of products that are oriented toward the needs of users, reconfiguring them by regarding them as systemic elements and conceiving them from the perspective of the mobility experience. Secondly, design is used consequentially to adapt elements of the transportation infrastructure that support cycling in

Fig. 5 Positioned between Autobahn A3 and Terminal 2, the bicycle bridge becomes an iconic symbol of the new mobility. (Source: Andreas Grzesiek/DML, HfG Offenbach am Main)

ways that improve the mobility experience. Not only can design be used to optimize the mobility system through product innovations, but it can be used to convey the importance of innovative and environmentally friendly mobility along the interface between the mobility system and users. This means using design in order to arouse curiosity while promoting acceptance of different or new modes of mobility and their use in everyday life. In this way, design can contribute to the emergence of new habits and routines, hence advancing the larger aim of promoting sustainable mobility.

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04 The project is a concept of the BikeBridge seminar at the University of Art and Design (HfG) Offenbach (supervision: Peter Eckart with Julian Schwarze) from the summer semester 2017. BikeBridge emerged from a student competition for a bicycle bridge in the framework of the sponsorship project Fahrradmobilität in großen Gewerbe- und Industriestandorten am Beispiel des Frankfurter Flughafens (Bicycle mobility in large commercial and industrial locations using the example of Frankfurt Airport), organized by the NRVP (National Cycling Plan). Partners in the project were the mobility department of the Regional Authority FrankfurtRheinMain and Fraport AG.

Road Closure as an Experimental Urban Design Tool Fostering Active Mobility

A Case of Frankfurt Mainkai Riverfront

Lakshya Pandit

Fig. 1 Mainkai street before, during, and after road closure in 2019, 2020, and 2021, respectively. Note: The cycle lanes in 2021 were painted permanently after data supported the initial recommendations presented to the Traffic Planning Department of Frankfurt am Main. (Source: Urban Design and Planning Unit, Technical University of Darmstadt)

Globally, the car as a mode of travel has played a dominant role in the urban mobility scenario, but in recent years many European cities and agglomerations have taken measures to encourage a paradigm shift away from the car by supporting green and active mobility (that is, involving walking and cycling in travel, which also promotes health-related benefits). According to previous urban studies in Germany, the majority of citizens have prioritized a car-less existence for a better way of life and favor alternative urban practices over car-centric approaches for their city or neighborhood (BMUB 2017). This perspective enables planning bodies to take measures, with the support of public opinion, toward active mobility in the future.

In 2019, one such measure was undertaken by the city of Frankfurt on the Mainkai riverfront. The northern stretch of 800 meters between the two bridges Untermainbrücke and Alte Brücke was closed to car traffic for a year, inviting diverse usage of space for the intermediate timeline. The closed street section was in proximity to the city center of Frankfurt, the Hauptwache plaza, and has elements of open green spaces near the riverfront. While the street was open to public use, no permanent design changes were permitted due to the temporary nature of the road-closure experiment.

Prior to the road closure, Mainkai street, which had no cycle lanes, was mainly dominated by cars. Movement via active means of mobility mostly occurred along the riverside boulevard, used by cyclists, kids, wheelchair users, pedestrians, etc. The riverside was seen as a space of conflict where fast-paced user groups (cyclists and e-scooters) would share the same space with slow-paced user groups (baby strollers, users with reduced mobility, such as wheelchair users, etc.). In addition, the uneven ground surface and the rail track in the middle of Mainkai led to some bicycle accidents (↳Fig. 1).

With the road closure in place, an impact study was undertaken after a year of its implementation, allowing for people to get familiar with the nature of the new open space. To initiate the impact study of the road closure, certain points were identified on the Mainkai and nearby streets (including the three bridges) to study pedestrian

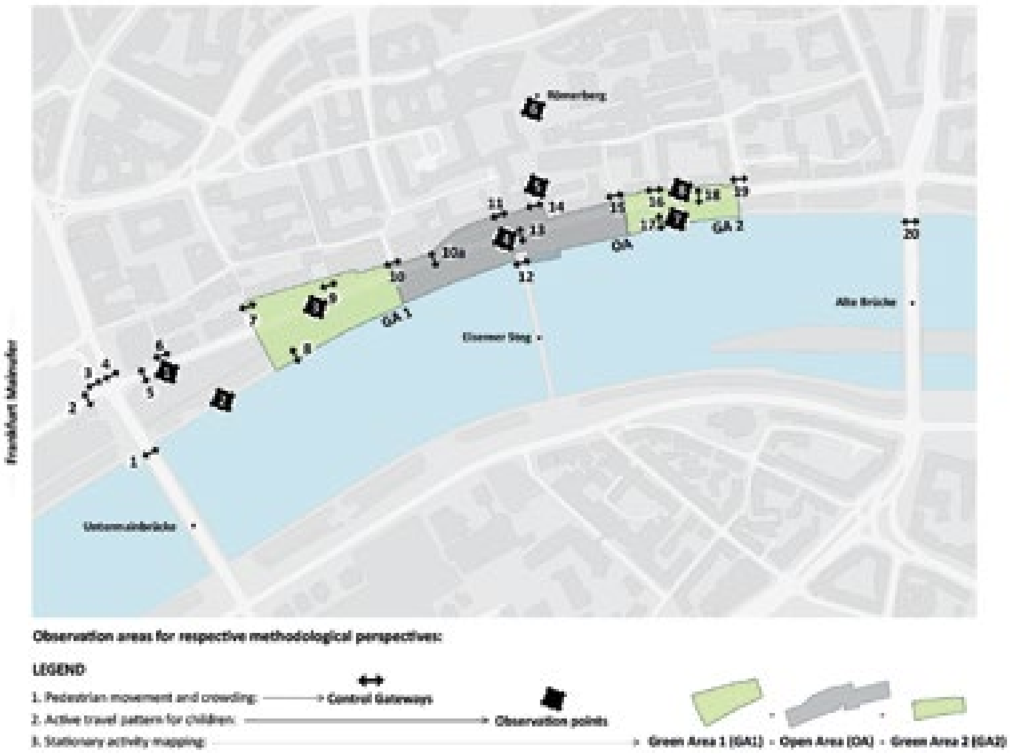

Fig. 2 Observation areas for on-site study in Mainkai, Frankfurt am Main (Pandit et al. 2020). Note: The Mainkai street was closed to vehicular traffic between gateway point 5 (near Untermainbrücke) and point 19 (near Alte Brücke). (Source: Pandit et al. 2020)

movement, the active travel patterns of children, and stationary activities (↳Fig. 2). The data collection was undertaken during the morning, afternoon, and evening peak hours on weekdays and weekends over a similar timeline over the course of three years, from 2019 to 2021. In 2020, with the onset of the COVID-19 pandemic, the closed stretch of Mainkai riverfront was seen as an opportunity for people to use the open space while maintaining social distancing. Overall, the open Mainkai street saw a 46 percent increase in cyclists and a 20 percent increase in pedestrians during the peak hours of the day after the road was closed. With respect to the vulnerable user groups children cycling independently increased by 1150 percent(!) and there were 25 percent more users with reduced mobility (URM) (Pandit et al. 2020). The results also showed a decrease among cyclists and e-scooters in the riverside area (gateway points 8 and 17 in ↳Fig. 2), suggesting they moved away from the space of conflict because they had had to slow down to accommodate other user groups. This showed the difference in utility of spaces among user groups based on differences in their speed of movement. It was clear that Mainkai street favored cyclists with a more direct path of movement, but it didn't have a dedicated bicycle pathway for them.

The road closure showed an increase of active modes of mobility on Mainkai street, supporting walking and cycling activities among children and adults. This in turn influenced the stationary activities, sitting and standing, which became more frequent around open spaces. More recreational activities on the street by local associations led to stationary activities, especially alongside the roadside edges, which were mostly unused open spaces prior to the road closure. The temporary benches installed on Mainkai street, which also became intermediate relaxation spots for cyclists on the street, propelled more activities. While the influx of tourists was reduced due to the lockdown measures in 2020, more local participation and availability of the street as a new open space enabled more utilization among pedestrians and other user groups (↳Fig. 3).

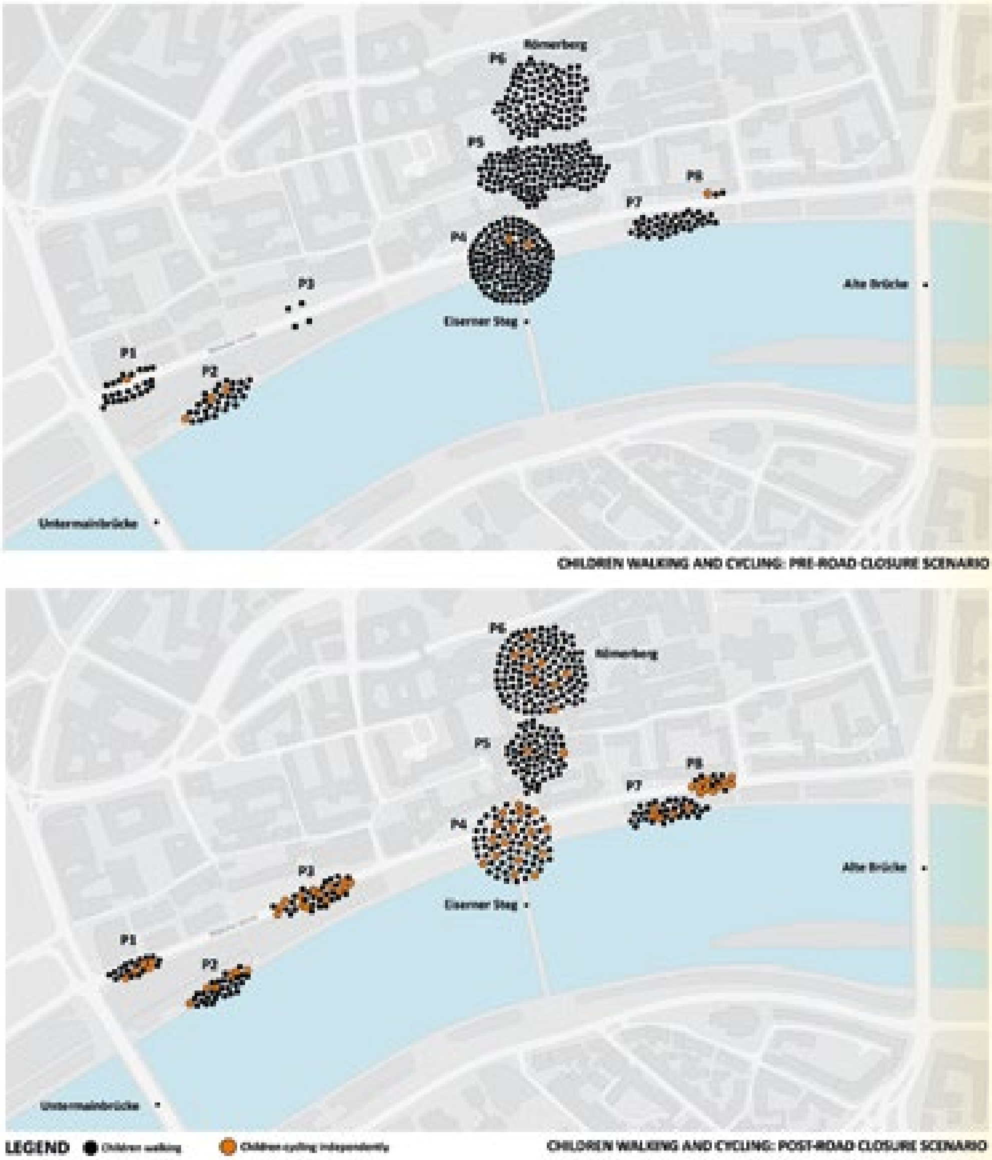

Fig. 3 Children walking and cycling independently during pre-and post-road closure scenario (Source: Pandit et al. 2020)

With the timeline of the road-closure experiment being temporary in nature, the Mainkai street was opened again to the car traffic later in 2020. This phase, the non-road closure scenario, was taken into consideration for data collection in 2021. After a year of opening Mainkai street back to cars, the situation led to decrease in cyclists' peak-hour density (down 8.2 percent compared to 2019) in the Mainkai area. While the number of cyclists reduced by around 5 percent on Mainkai street, the riverside area showed a greater drop of 25 percent. This shows the acquired movement of cyclists still favoring the Mainkai street through the behavior learned during the road-closure experiment. On Mainkai street, there were more pedestrians (up 21 percent) along with e-scooter users, which showed the maximum growth in peak-hour density (a jump of 175 percent) in comparison to pre-road closure scenario. The vulnerable groups including users with reduced mobility showed an increase of 31 percent (in comparison to 2019) on Mainkai street. With cars being back on the road, the impact on cyclists using the street was clear and it showed the discomfort with a reduced peak-hour frequency of cyclists (↳Fig. 4).

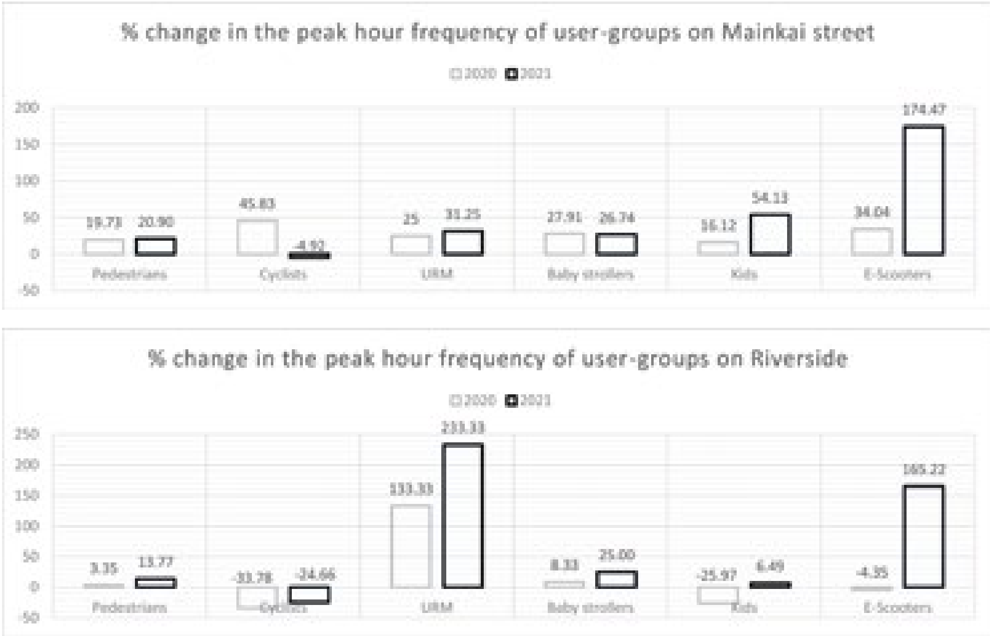

Fig. 4 Change in peak-hour frequency of user groups on Mainkai street and Riverside in 2020 and 2021 (in comparison to 2019)

Fig. 5 Active and stationary activities on Mainkai street during the road-closure experiment in 2020 (Source: Lakshya Pandit).

While the slow-moving user groups (pedestrians, users with reduced mobility, people with strollers, kids, etc.) increased to a certain extent on the Mainkai street in 2021, the fast-moving user group—cyclists—decreased. The road closure might have been responsible for attained user behavior of using spaces in close proximity to the Mainkai street; though with car traffic back on the road, the reduced freedom of movement among cyclists without a dedicated bicycle pathway could account for reduced numbers. During the summer of 2021, a permanent change on the Mainkai street was observed; a car lane was replaced with a two-way red cycle lane on the sides of the Mainkai street. The move would influence the stationary activities taking place along the edges of Mainkai street, making them safer, as they were more distanced from the high-speed car traffic. The new bike lanes would also support the growing trend for bicycle users, which was observed in 2020 during the road-closure experiment, and propel movement toward achieving higher modal split for cycle as a mode of travel. While the dedicated bicycle pathways are not as wide as those seen in cycle-friendly cities like Copenhagen (2.5 meters) (Gehl 2010), the move would propagate the drive for having for more cycle-friendly streets around the city.

The practice of street closures has been prominent in cities with a focus on population health, active modes of travel, and related subject areas. In the USA and other countries, many cities have undertaken large-scale road closure measures (also known as ciclovías) as a medium to promote physical activities within its population. A road-closure initiative via summer streets in New York engaged many people into walking, running, cycling, and other physical activities (Wolf et al. 2015). With cities trying to provide more space for children, the implementation of play streets, which provides a safe environment for children and their caretakers, has been another type of temporary road closure. Such measures have shown increased amounts of physical activities and a greater sense of community (Umstattd et al. 2019), which has a positive impact on an individual's health. The examples of ciclovías and play streets showcase the practice of street closures in urban spaces becoming more frequent, especially with a focus on fostering more physical activities through different user groups involving children as well (↳Fig. 5).

Mainkai as a shared space has seen continuous changes over the years, with the experimental nature of the road closure showing its potential for different user groups favoring active mobility. Similar short-term experiments have been observed during the pandemic in neighboring cities forming the Rhein-Main agglomeration, offering an opportunity to check a street's potential toward active mobility modes and to find ways to improve its present modal share, ultimately supporting alternative urban practices over car-centric planning approach in cities and neighborhoods.

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Augmented Mobility

Reinventing Public Transport

Autonomous Fleets in Place of Public Buses

Weert Canzler
and Andreas Knie

From Driving to Being Driven

The transformation of transportation appears irreversible. An important step along the way toward the electrification of drive technology is a vastly more efficient organization of transport resources, with fewer private automobiles, a significant transition toward resource-conserving public transport, and more cycling and walking. Although the transformation of transportation is a global topic, we place our focus on examining the case of Germany, as this country can be seen as one of the biggest automobile strongholds. This article asks whether this supremacy of the automobile industry in Germany can be diminished. We argue that, while we will witness the transition to autonomous driving in the foreseeable future, the German automobile industry as well as the public transport sector are currently failing to recognize the concomitant opportunities. With the question raised of whether autonomous driving is part of the solution or the problem, it becomes evident that political guidance is needed. Required are not just conducive regulations, but also ambitious providers in the public transportation sector and a fundamental reconceptualization of the automobile industry. It is a question not only of radical technical innovation, but also of a paradigm shift in transport policies: a transition from driving to being driven.

The aim is comprehensive mobility with a smaller number of vehicles and a radical reduction in resource use. When it comes to autonomous driving, the current focus of both experts and the media is on the conventional automobile. Since the 1960s images of driverless cars, whose occupants no longer need to steer and can while away the time with board games have dominated the media. But autonomous driving need not necessarily be conceived as a continuation of private automobility. A completely new perspective opens up provided we imagine the development of autonomous vehicles as representing a shift toward a radically modernized, multi-optional, public transport service. Passengers could be driven from door to door in vehicles having a variety of sizes and amenities. This specific way of using the vehicles is generally denoted by the futuristic term *robotaxi*. The word conveys an extreme degree of automation: there would no longer be any human drivers, and passengers would have no influence on the driving process. Vehicles would operate autonomously, their assignments preprogrammed, and would be surveilled remotely within a defined territory. In this case, it is therefore useful to distinguish autonomous driving, which implies a driverless, independent vehicle, distinguished from automated driving, meaning technology that provides a support function for private automobiles that are controlled by human drivers.

In recent years, discussions about automated and autonomous driving have been conditioned by internationally agreed-upon levels of automation; the currently prevailing Level 2 is expected to transition all the way to fully autonomous driving, referred to as Level 5. Implicitly, the dominant model of the private automobile is to be perpetuated, with the successive introduction of additional assistive functions. Foregrounded are concerns about greater comfort, convenience, and safety for private automobiles as we know them today. The race to claim the prerogative to identify the potentials of autonomous driving, beyond safety and function, has only just begun (Canzler et al. 2019).

When it comes to automated driving, announcements about which kinds of vehicles will be traveling our roads and when and how they will revolutionize street traffic are reaching us almost on a daily basis. There is a tendency to use the terms *automated* and *autonomous* interchangeably. As a rule, these terms are used to refer to partially automated vehicles, since we have no actual experience to date with fully autonomous vehicle fleets. In the United States and China, however, test vehicles produced by various digital companies are being operated in real conditions, and are gathering many test kilometers of experience, or stated more precisely: they are collecting data in order to learn. In particular, the Google subsidiary Waymo has accumulated a substantial wealth of experience, establishing a considerable lead over competitors.

In examining these developments and test projects, a fundamental difference between European and US cultures of innovation becomes conspicuous. In Europe, pilot trials are being undertaken in protected laboratory situations, for the most part on hermetically sealed test tracks preceded by strict premonitoring, and only after elaborate approval procedures. In the United States, in contrast, testing is conducted in real street traffic with one or two occupants who can intervene in emergency situations, and of course in compliance with current regulations. Here, in contrast to Germany, the vehicles do travel in real-life conditions and are exposed to erratic street traffic. With the digital enterprises in California, the preparedness to engage with risk and to undertake technical adaptations through trial-and-error procedures is far higher than with European auto manufacturers (Canzler and Knie 2016; Daum 2019).

Alongside technical and legal challenges, however, it still remains an open question which model of use for automated—and later autonomous—vehicles will ultimately prevail. The visions of the traditional automobile manufacturers diverge essentially from the aims of the US tech enterprises.

The large auto manufacturers are working on the stepwise construction of driver assistance systems such as the »Traffic Jam Chauffeur« and the »Highway Chauffeur.« These make it possible for drivers who find themselves stuck in traffic or traveling on freeways to relinquish the steering wheel, at least intermittently, and turn their attention to other activities. These technologies, as expected, are being introduced together with expensive and elaborate technical add-on systems via the luxury segment. In engineering language, this step can be described as the transition from Level 3 to Level 4 of automation logistics.

A major theme throughout this development is »takeover time,« the period of transition from automated steering back to human driving. At this point, no accepted standards exist in this regard. The central problem yet to be resolved is to distinguish at which exact point the responsibility of the human driver stops and that of the machine begins. Clarity about this process is required for accidents to be avoided. User acceptance will only occur if this transition can be achieved in a stress-free manner (Stilgoe 2017). The question is: Which activities, apart from driving, will the person in the vehicle be allowed to do, and how quickly should that person have to change from a passenger—who is likely in a relaxed state, or even a state of semi-sleep—to an active driver (Wolf 2015)?

In general, it is important to ensure that during disturbances or in emergency situations, the passenger in a partially automated vehicle can intervene. Paradoxically, this becomes more difficult the more rare emergencies are. There is a considerable danger that passengers will »unlearn« driving skills and require too much time to find their way back to the unaccustomed role of the driver. Difficulties involving this so-called handover to a human driver have plagued pilot projects with partially automated vehicles for years now, and the problem remains unresolved (Morgan et al. 2017).

A series of research projects has tested rules and technical warning signals designed to facilitate takeover by passengers. Looking at the focus of the current research projects and questions involved makes clear that vehicle manufactureres still adhere to the classical model of the private automobile. Automobility is becoming simpler and more comfortable, while the actual business model is to change as little as possible. As of summer 2021, German manufacturers, for example, had not yet succeeded in offering a technically reliable solution that could actually enter production. In this regard, the design decision to continue to center the human as the driver of the car even when it comes to automated driving has resulted in a technological dead end.

An entirely different vision is being pursued by US digital enterprises. With every test mile driven, Google (Alphabet), with its subsidiary Waymo, optimizes its algorithms for genuinely autonomous driving with the assistance of artificial intelligence. In selected areas, the test vehicles, as robotaxis, offer comprehensive point-to-point services without any driver intervention, relying on a combination of radar, camera, and lidar (light detection and ranging).

Before a Waymo vehicle rolls onto the street, it is equipped with a detailed data map of the driving environment, with information about streets, crossings, and fixed objects lining the roadway. Such prior knowledge concerning permanent features of the operational terrain allows the sensors to focus on moving objects and other road users.

When it comes to weighing their technical options, Waymo and other digital companies such as Cruise and Uber remain »open.« They are confident that products and services that have demonstrated their large-scale practical value will find a suitable commercial model, even where current operations have failed to show positive quarterly results. This means that neither strictly commercial key figures nor ecological indicators count as benchmarks for the strategic success of these companies; what counts instead is a larger vision. Nonetheless, they do rely—and it is here that the European enterprises regularly underestimate the American competition—on functional blueprints. After all, the imagination of capital providers is only genuinely inspired when evidence of success can be demonstrated, at least in principle, in well-defined subareas.

Neither the consistent automation of private automobiles nor the vision of truly autonomous robotaxis is being pursued in earnest by the traditional automobile manufacturers. In particular, the idea of autonomous fleets seems to be seen more as a variety of public transport. And neither vehicle manufacturers nor platform operators have sufficient experience with managing vehicle fleets in public space. It is also questionable whether they bring the necessary empathy to the task. After all, transport is necessarily public in character, as it serves collective transport objectives and always involves a mixture of political and entrepreneurial interests. For this reason, a municipality or region that commissions public transport services may compel operators to provide service in areas and on routes where demand is weak, even far below the threshold of financial viability. In order to resolve this contradiction, German cities and municipalities often operate transport services themselves, covering deficits with their own budgetary resources, or advertising bids for such services and paying private operators with public funds. It is not uncommon for a certain type of service to be considered in the public interest, even though it would not be regarded as viable from the perspective of a for-profit enterprise.

Neither in Europe nor in North America would the established operators of public transport services—largely rail or bus companies—be able to generate the requisite investment or to marshal the required competencies to embark upon the development of robotaxis. When it comes to the technological development of automated driving, the real impulse comes from the digital enterprises. In contrast, public transport companies—including Deutsche Bahn—have not played a major role to date in the race to develop this technology. Repeatedly, these enterprises are instead relegated to their core priority, namely rail transport, a sector that has fallen behind when it comes to the necessary modernization measures.

The current intermediate stage of semi-automated vehicles—whether in the form of partially automated private automobiles from the major manufacturers or robotaxi prototypes by Waymo and others—raises the question of which technological developments are deemed beneficial when it comes to climate-protection goals, an envisaged redistribution of public transportation areas, and the general improvement of quality of life, and which ones conflict with these political objectives (Dangschat 2017; Fleischer and Schippl 2018).

Up to this point, we lack suitable protagonists when it comes to developing autonomous vehicles as integrated elements of an attractive public transport system. Neither platform operators nor automobile manufacturers have sustainable or socially equitable public transport in mind—their aim is simply to market their services or vehicles profitably. The development of autonomous vehicle systems for the sake of modernizing public transport is therefore ultimately a political question as well. The design task consists of using autonomous driving as a component of a multi-optional and environmentally friendly mobility, or, in other words, part of a transformation of the transport system. It is a question of shaping the framing conditions of transport, or of modifying existing regulations in such a way, that automated vehicles are integrated into a multioptional transport structure (Knie and Ruhrort 2019). This means exploring the potential for the development of automated vehicles to play a key role in a transport system that is both ecologically efficient and compatible with urban life, and that could improve transport connections in rural regions. Possible are hitherto unconventional forms of cooperation, such as that between the South Korean automobile manufacturer Hyundai and the US ride-hailing business Lyft, which could provide public transport services.[01]

In addition to cost savings, one advantage of (partially) automated shuttles over conventional buses is that they can be deployed far more flexibly and are far more adaptable to changing topographical and infrastructural conditions. The range of application includes connections to stops and stations (»hubs«), serving residential areas, and also operating in industrial parks, hospitals, schools and institutions of higher learning, in an on-demand mode in the form of shuttle services (»spokes«). While transport volumes are reduced due to limited capacity, flexibility is increased when it comes to types of service and schedules is substantially larger than with conventional buses. Even conventional bus route operations can be covered using shuttle systems during off-peak hours (Hunsicker et al. 2017).

At the moment, (partially) automated shuttles are still far from ordinary operational capacity. Regarding both technical and legal standards, many technical and operational questions have yet to be resolved. Currently, there exists a substantial gap between the technical standard attained and robust serial operation, while economies of scale cannot be achieved as yet.

When attempts are made to introduce such a system, a basic problem in the public transport sector becomes clearly evident. In comparison to other industries, it is not just financial clout that is absent; it is the lack of a culture of innovation that prevents the operators of regional and local transport systems from catching up. In their legal constitutions, public transport operators, as well as networked municipal transport authorities and special purpose associations, are not geared toward addressing open, future-oriented topics. The transport operators are operative providers, while the commissioning organizations were set up for the purpose of the legally tendering of standardized transport services. Competitive bidding proceeds exclusively at the level of costs. The logic of the public transport system hinders innovation because it is not represented in the system, much less rewarded (Canzler and Knie 2016: 39ff.).

Reinventing Transportation in Germany, the Land of the Automobile

A genuine alternative to the private automobile will emerge only if new forms of modernized public transport are convenient, reliable, and flexible. Under the conditions of the Personenbeförderungsgesetz (German Passenger Transportation Act; PBefG), which was modified in August 2021, on-demand transportation on the basis of digital platforms can contribute to achieving the target vision of sustainable, efficient mobility. Interlinked with classical bus lines to form an overarching service, on-demand offerings could provide an alternative to the private automobile. The larger question is: How can a reorientation of transport policies avoid having flexible mobility offerings—and potentially fleets of automated vehicles—simply generate a rising flood of barely used private automobiles in cities? How can it lead instead toward reducing the number of vehicles by providing highly efficient public fleets and door-to-door services?

In essence, the use of (partially) automated vehicles opens up additional public transport options, and can therefore enhance its attractiveness. Rural regions already have great potential when it comes to implementing (partially) automated shuttles. Gaps in a hub-and-spoke concept can be filled in, and the preconditions for such transport models are easier to establish in rural areas. From a fiscal point of view, shuttle systems not only offer greater flexibility, but also promise distinct advantages in comparison to buses in the mid- to long-term by virtue, for instance, of their substantially lower operating costs.

To summarize, if the necessary political framework were in place, automated vehicles in the form of autonomous fleets would make a considerable reduction of vehicle numbers possible. Whether autonomous fleets actually arrive, and whether they turn out to be a blessing or curse is less dependent upon technological developments than on the political will of the regulators. If climate targets are to be taken seriously, and if the transformation of the transportation system and the objective set of targets outlined here are to be pursued in earnest, then automated vehicle systems will have to play a strategic role.

An additional requirement for achieving this target vision, and for making possible on-demand offerings in public transport with potentially autonomous vehicle fleets, is to ensure that the collective use of vehicles is not only authorized, but that adequate space is also provided for their use. The objective must be to ensure that a steadily growing share of public space is reserved for the most efficient modes of transport. Exclusive—which is to say private—vehicles must be charged a substantially higher fee for the use of public space, and public parking spaces for private vehicles should be strictly limited. The car-sharing law adopted by the Bundestag in 2017 made it possible in principle for the municipalities to privilege shared autos in this way. It is left to the local authorities to actually exploit this legal basis by reserving public space for car-sharing vehicles.

Currently, the parking of all types of motor vehicles is allowed by German road laws as an aspect of »general use« vis-à-vis traffic. This is understood to mean that the parking of private vehicles has become established as a quasi-natural and unalterable »transport need.« Transportation planning has had to take this into account. In view of the goals of climate protection, this logic now appears obsolete, especially in light of the current potential of new intelligent mobility offerings. Reformed traffic regulations could exclude private vehicles from using public space in accordance with the Swiss model (Notz 2017; Agora Verkehrswende 2018; Ruhrort 2019). This would mean that non-transient parking in public space would only be possible where explicitly permitted. On this basis, communities could decide at which locations and to what extent, if at all, valuable public space could be made available for the parking of private automobiles.

An altered legal framework, however, is only one aspect of the needed reforms. What is also missing is a culture of experimentation. In Germany, providers of public transport are fixated on managing the operation of buses and rail vehicles, and are disinclined to test out new ideas (Canzler and Knie 2016). In order to enhance the preparedness of public transport operators to seize upon innovative approaches, the Federal Ministry of Digital and Transport, together with the Federal Ministry of Education and Research, could organize a number of real-life tests. Such a framework would make it possible for manufacturers of rail vehicles and buses, in collaboration with operators, subcontractors, and research institutes, to develop and test such systems outside of normal operations.

It will be important that there is a low threshold access for operators, and in particular that application scenarios are tested in public space in collaboration with municipalities and other regional authorities. Beyond this, the central question is whether and to what extent the largely municipal public transport companies succeed in developing the necessary trial-and-error culture.

New Options in Germany: An Invitation to Autonomous Driving

Concerning the question of whether autonomous vehicles are a blessing or curse, far more is at stake than simply a new means of transport. Ultimately, it is a question of the modernization capacity of the mobility sector. At the center stands the German automobile sector, which has long profited from the continuing fixation on private vehicles. However, generally changing attitudes toward the automobile, the pressure to electrify the powertrain, and of course the diverse, widely circulating visions, are having an impact on the industry.

On-demand transport operations, automated shuttles, and the prospect of autonomous vehicle fleets could become a game changer: they have the potential to fundamentally change the transport landscape. But such fleets are not going to simply

01 Ioniq 5 Robotaxi: »Elektro-Hyundai zum Mitfahren,« in: *Autohaus* (August 31, 2021), https://www.autohaus.de/nachrichten/autohersteller/ioniq-5-robotaxi-elektro-hyundai-zum-mitfahren-2929687.

drop from the (Californian) sky to become accessible on German roads overnight. Instead, they need to be made possible on a political level, and we will need to shape their interface with existing public transport resources. Surprisingly, creative freedom has already been created through the Gesetz zum autonomen Fahren (German Act on Autonomous Driving), which was adopted by the German Bundestag and the Bundesrat in spring 2021. More precisely, it is an »Act that changes regulations governing road traffic … to allow it autonomous driving, as well as on an ordinance on the approval and operations of motor vehicles with autonomous driving functions within delimited areas of operation« (Autonome-Fahrzeuge-Genehmigungs-und-Betriebs-Verordnung; Autonomous Vehicle Approval and Operation Ordinance—AFGBV).

Regarding their purpose and application, these regulations are unique worldwide because they expressly permit autonomous fleets to operate on public roads. Accordingly, it now becomes possible—within a specified area of operations—for a vehicle to be controlled not by a human driver, but instead by a »technical supervisor« that is not stationed in the vehicle. This establishes the legal preconditions for the envisioned paradigm change in the direction of partially automated driving. Through proactive regulations, and in light of the progress currently being made by digital enterprises, a practical opportunity exists for making autonomous fleets of vehicles a component of an up-to-date, flexible public transport system.[02]

A much-noted simulation study carried out by the International Transport Forum outlines a scenario within which autonomous shuttles serve the general public, and could already be implemented today if used in order to supplement a functioning public transport infrastructure, and provided that efforts are made to radically reduce the number of private automobiles (ITF 2017).

Driverless vehicles would then emerge as a new public transport option and would achieve a high degree of individual serviceability in combination with larger high-performance vehicles. Based on empirical studies, it becomes possible to estimate that a system of fully automated shuttles—one that is embedded in a hub-and-spoke system—would make it possible to reduce the number of vehicles in cities to around fifty vehicles per 1,000 inhabitants. This would mean an inventory of automobiles that would be just one-tenth of the present number (ITF 2015, 2017, 2018). Of course, these calculations are context-dependent, and are valid for European cities only. Studies from other parts of the world, such as the United States, cannot be extrapolated elsewhere given the utterly different settlement and transport structures present there (Canzler et al. 2019).

Concerning the implementation of (partially) automated shuttles as a component of the public transport infrastructure, further action is needed. The current design of vehicles, along with the media needed to employ them, and especially the intermodal connection points of a hub-and-spoke system still require considerable adaptation when it comes to interface layout. People can only be persuaded to use an intermodal option provided they are able to negotiate the system and have trust in it. This is not at all the case for currently available options, which were developed and optimized in complete isolation from one another. In the automobile industry, an awareness of the relevance of design and professional symbolic user elements is nothing new. But for the public transport sector and the authorities responsible for commissioning it, these aspects have played almost no role up to now.

Emerging—although much remains to be done, and a number of questions still need to be resolved through real operations—is a situation that is atypical for Germany, one in which the legal preconditions for the reconfiguration of the transport system are present, but the entrepreneurial capacity that would allow these options to be exploited is lacking: the automobile manufacturers do not want to do it; the public transport authorities cannot.

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Virtual Reality in Mobility Design

Experimental Research on the Application of VR Simulations

Julian Schwarze,
Kai Vöckler,
Stephen Hinde,
Erwan David,
Melissa Le-Hoa Võ,
and Peter Eckart

For the design of public mobility, the perspective of users is fundamental: how can their needs and expectations be integrated into the design process? By virtue of their spatiotemporal experiential quality, virtual reality simulations have the potential to convey the actual impact of designs and planning measures on users more effectively than traditional forms of representation such as renderings or plans. Through collaborations between experts from the areas of cognitive psychology and design research, the research project »Cognition Design« (CogDes) explored the questions: to what degree are virtual reality simulations adapted to investigating the impact of design decisions on users? And: how realistic do such simulations need to be if they are to lead to well-founded conclusions concerning the impact of the simulated situations on users? The research project is a joint project of the Scene Grammar Lab of the Department of Psychology at the Goethe University in Frankfurt and the Design Institute for Mobility and Logistics at the University of Arts and Design Offenbach.[01]

Virtual Reality Simulations as Test Environments

When it comes to determining the impact of design decisions on user perceptions, new technologies in virtual reality (VR) appear quite promising. These make it possible for users and researchers to encounter one another in a simulated space featuring a high degree of realism. VR simulations have features that make them especially well-suited to investigating complex perceptual processes. First, so goes this argument, they are immersive in a way that is impossible for either laboratory environments or renderings and plans to achieve. This makes it possible to compare actions and experiences in real space. In VR, secondly, it becomes possible to compile comprehensive scientific data in a controlled way: the simulation of various mobility environments with a range of variants facilitates a systematic investigation, based on cognitive psychology, of the impact of design decisions (for example, lighting and lighting control, object positioning and object design, surface design, the arrangement, density and design of information in the form of images and texts, spatial structuring, etc.) on users.

If it is indeed true (to return to our initial question) that the virtual environment, with its spatiotemporal experiential quality, is genuinely comparable to experiences in real space, this would make it possible to develop a valid foundation for design decisions on the basis of tested spatiotemporal multiuser experiences. From the perspective of design research, then, VR simulations make it possible—at a relatively low cost—to test planning and design variants for mobility spaces and hubs systematically with the assistance of methods from cognitive psychology (↳Fig. 1).

Virtual reality is an ideal environment for studies in cognitive psychology. VR models are used in psychology to an increasing degree, since they ensure a high degree of experimental control while offering the ecological validity of a realistic, non-laboratory-technical environment. The latest eye-tracking technologies, which are integrated into VR headsets, permit the precise registration of processes of attention in space and time. Through the systematic analysis, both in the real reference

01 The project was sponsored by the German Federal State of Hesse (Ministry of Economy, Energy, Transport, and Housing) and the HOLM Innovation Funding in the framework of the measure »Innovations in the Area of Logistics and Mobility« (HA Projekt-Nr. 817/19-137). In terms of content, it arose from the research conducted as part of the LOEWE research cluster »Infrastructure—Design—Society« (sponsored by the Hessian Ministry of Higher Education, Research, Science and the Arts through the Excellence Program of Hesse). The team consisted of research staff and students from the Goethe University in Frankfurt (cognition psychology): Leah Kumle, Leila Zacharias, Teresa Schnorbach, Julia Beitner, Stephen Hinde, Erwan David, and Melissa Le-Hoa Võ (project leader); and the HfG Offenbach University of Art and Design (design): Annika Storch, Luke Handon, Ken Rodenwaldt, Robin Schmid, Julian Schwarze, Kai Vöckler, and Peter Eckart (project leader). Project documentation is available at https://immersitylab.org.

Fig. 1 Experimental research and data collection through the application of virtual reality test environments (Source: Julie Gaston; Julian Schwarze, Design Institute for Mobility and Logistics, HfG Offenbach)

situation as well as in the simulation, psychologists acquire knowledge concerning the ways in which real and simulated situations are comparable, thereby potentially laying the groundwork for subsequent research.

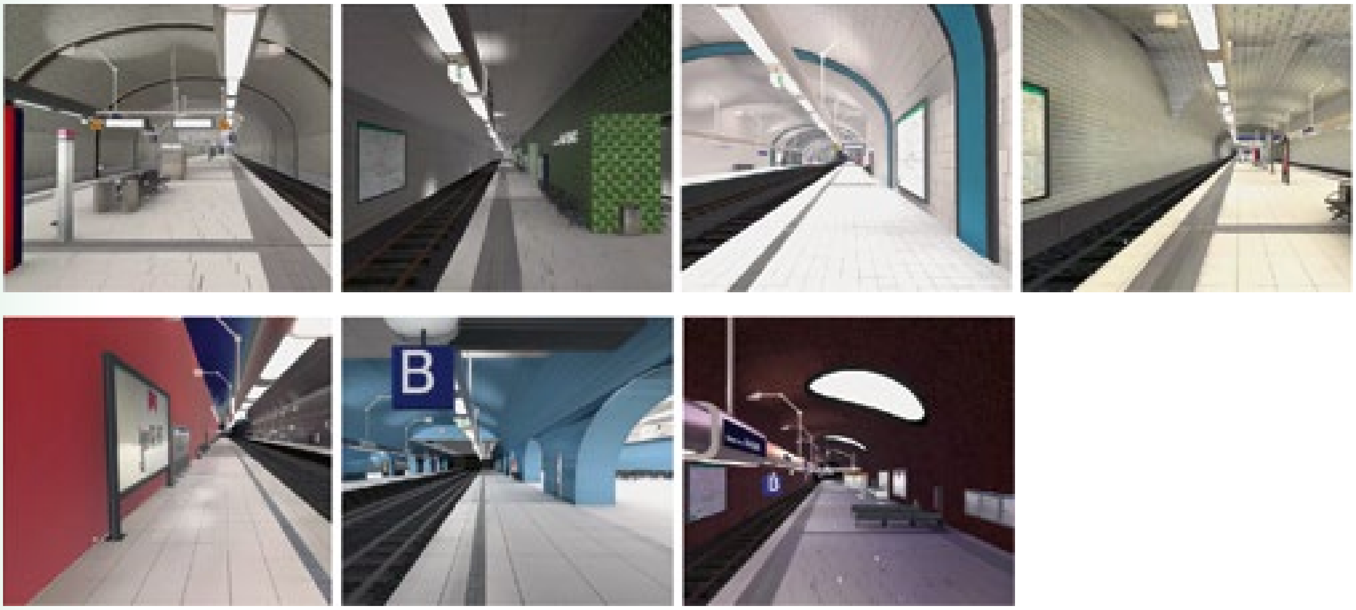
Delimiting the Area of Investigation

Developed and tested in the project, based on a typical mobility situation (the subterranean level of a commuter rail station), are simulations having varying degrees of realism—from a relatively abstract test environment (laboratory situation), all the way to the integration of richly detailed operational, movement-based, and experiential options. The latter might include the greatest possible freedom of movement and extend to the formulation of realistic tasks that are to be fulfilled by the test subject. In order to arrive at reliable conclusions, the focus of the project was on the visual experience of a subterranean, multileveled commuter rail station. The target of investigation was the wayfinding from the entrances to the station via a B level to the train platform, set lower down, subdivided into a sequence of spatial interactions. An analysis of processes of attention, both in the real reference situation as well as in the simulated situation, led to conclusions concerning the degree to which real and simulated commuter rail stations are comparable, taking into account the fact that social interaction could not be simulated in the VR experience. Correspondingly, the investigation focused on individual and psychological experience during utilization. Socioemotional factors of influence and symbolic meanings of the kind that emerge from the individual's social milieu were not investigated. Previous experience on the part of the test subjects, where applicable, was taken into account, but all olfactory, auditory, and haptic perceptions (and the thermic influences associated with them) were not considered since these could not be simulated, at least not adequately. Therefore, the principal focuses were functional aspects of spatial orientation and the subject's understanding of visual information (textual and graphic symbols) while navigating the mobility space, which is essentially dependent upon visual understanding (↳Figs. 2a+b).

Interdisciplinary Methodological Approach

Methodologically, nomothetic and ideographic approaches in the study were interconnected. This encompassed qualitative and quantitative surveys, the tracking of attentiveness, the analysis of behavioral patterns, and physiological and psychological methods of measurement. Quantitative measurements were data from the act of use, while the act of measurement avoided influencing or altering user behavior. The recording of eye and head movements (eye- and gaze-tracking) in the VR environment made it possible to investigate the

Figs. 2a+b Comparison of a real space and its digital twin through the application of virtual reality technology and eye-tracking (Source: Julie Gaston)



Figs. 3a–g Illustration of the seven simulated commuter rail stations, accessible with VR glasses (Source: Design Institute for Mobility and Logistics, HfG Offenbach)

influence of various design approaches on attentiveness. Beyond this, eye-tracking technologies were used to classify, categorize, and analyze the simulation and its prominent visual features (salience). The measurement of attentiveness formed an important basis from which conclusions concerning the effectiveness of design decisions could be derived. Interpretative phenomenological interviews (interpretative phenomenological analysis, IPA; Smith 2009) allowed the phenomenological experiences of users to be taken into account. These were correlated with the results of quantitative measurements. The research project linked together analytical approaches from design theory (theory of product language) with the experimental analytical methods of cognitive psychology (scene grammar), and transferred these onto a three-dimensional, experiential test situation; findings concerning wayfinding from architectural and design theory were integrated as well. The objective was to produce a scientifically valid basis for the evaluation of design measures and their impact on users. The project should therefore be regarded as experimental basic research.

Theoretical Background

In a first step, the project partners merged their various theoretical approaches and derived the structure of the investigation from the results. In cognitive psychology, the term *scene grammar* (Võ 2021) refers to an approach that defines hierarchically structured rules that are associated with a visual scene (the space), which then facilitate object perception as well as visual search. These rules are extracted from specific episodes of spatial interaction and allow us to make predictions about the location of objects, while facilitating our perception of objects and directing visual attention efficiently within the space. The term *grammar* refers to the analogy between the way in which we learn scene grammar and the way we learn a mother tongue. In both cases, no explicit training is required; instead, expertise is acquired through continuous interaction with the environment. Like a language, this type of grammar can be applied to completely new situations (with language, unknown sentences; here, unknown spaces), thereby facilitating our understanding and interpretation of and interaction with them. A number of valid studies of scene grammar demonstrate that this functions effectively in relatively well-ordered artificial environments such as living rooms and kitchens (Võ et al. 2019; Võ, 2021). Lacking, however, are studies that show how scene grammar functions in public environments such as train stations, airports, and shopping centers, and in the corresponding VR simulations. The focus on a test environment in the context of public local mobility raises the question of whether this approach is genuinely suitable.

The theory of product language, developed in the late 1970s at the HfG Offenbach University of Art and Design, defines the functions of products as resulting from an interaction between human and object, and distinguishes between practical and »product language functions« (Gros 1976, 1983). Belonging to product language functions are formal-aesthetic functions on the one hand and indicating and symbolic functions on the other. The formal-aesthetic functions pertain to syntax, which is to say to the product's formal structure, and hence to the product's sensual-perceptible characteristics, independent of its substantive meaning (Steffen 2000). But it is not a question here of a set of rules, as with the grammar of a spoken or written language where linguistic units are combined according to conventions (through fixed linkages: syntax). Instead, the formal-aesthetic functions pertain to structural and formal features of products and the ways in which these are interpreted as forms in acts of perception. Inherent in the perception of products is the mostly unconscious, cognitive processing and evaluation. Attention to the theoretical background of scene grammar and to the empirical results it yielded resulted in an expectation of heightened validity for the method of investigation, based on product language.

Experimental Set-Up and Procedure

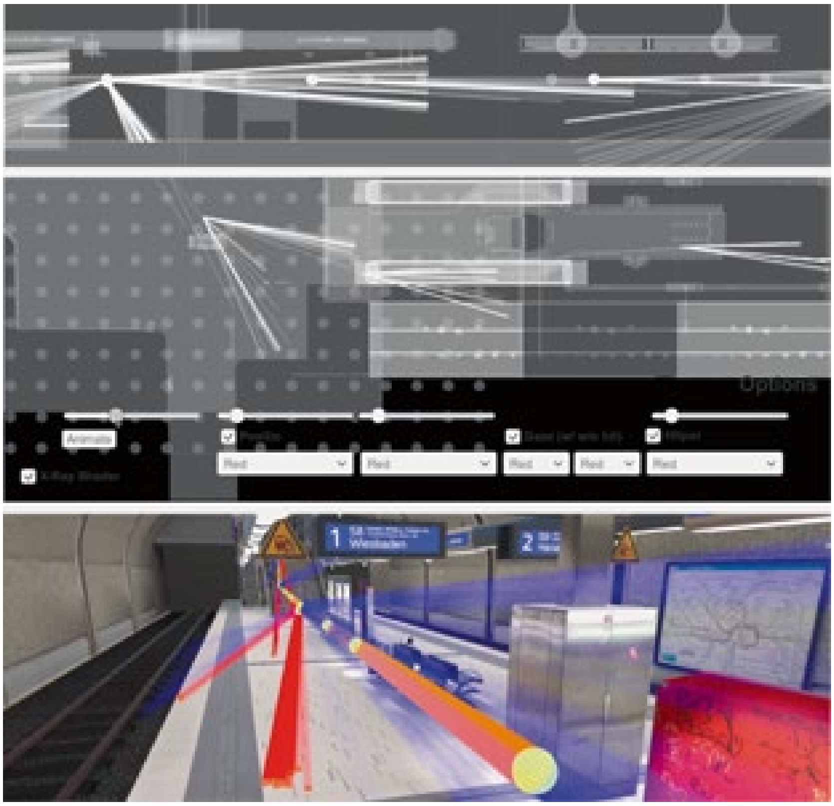
Perceptual and cognitive processes were investigated through VR simulations. This proceeded in two steps, each with a specific research focus:

1. A comparison between the real situation and the virtual reality simulation (current situation) sought to evaluate the validity of the investigation itself; the focus was on the impact of the simulated space and the VR technology (immersion character and sense of reality).
2. Various design measures and their impacts on users (with respect to orientation in space and of information acquisition) were investigated using VR test environment. Then a further six spatial variants were developed on this basis of the digital twin of the real situation.[02]

The point of departure was a digital twin of the Offenbach Marktplatz Station, which made it possible to carry out tests and cross-comparisons between a real situation and its virtual double. In order to record and measure immersive experience in the simulation, it became possible to develop virtual-reality variants for quantitative eye-tracking tests and follow-up qualitative surveys. The developed VR model (»testbed«) consists of seven stations, each with three levels: an entrance level beginning at street level (Level A), an intermediate level with service offerings and waiting areas (Level B), and a platform level for arriving trains, waiting areas, and service offerings (Level C) (↳Figs. 3a–g).

Eye-tracking technologies were used in both the simulated situation as well as in the real reference situation, making it possible to analyze the cognitive influences of design decisions as mediated by degrees of attentiveness. It was also a question of evaluating the ecological validity of the VR test situation in comparison with its real twin. This

02 The COVID-19 pandemic required adaptation of the virtual-reality testing and eye tracking. In response to the necessary hygiene measures, the number of subjects for virtual reality testing was reduced to sixteen, and for testing in the real situation, to just three. In terms of age and social status, moreover, the group of test subjects was fairly homogenous: the participants were primarily students (eighteen to thirty-five years of age) and would need to be more strongly differentiated in subsequent studies. Individuals with physical limitations should be a priority of investigation. In our view, the selection and number of test subjects for investigating the functionality of the virtual reality simulation in the test situation was adequate, and made it possible to arrive at a basic assessment.



Figs. 4a–c Representation of eye-tracking and walking routes and visualization of data gathered during the VR experiment (Source: Ken Rodenwaldt, Design Institute for Mobility and Logistics, HfG Offenbach)

then formed the basis for a continuing investigation of design measures and resources in the correspondingly varied test situations. Eye movements measured visual attentiveness and individual »task performance,« that is, success in achieving certain set tasks. Data on eye movements with respect to their spatiotemporal distribution in real and virtual space were then studied by comparing scan paths or fixation distributions. This made it possible to infer that the respective patterns of attention corresponded structurally (although the validity of these conclusions were limited given the reduced number of available test subjects due to the COVID-19 pandemic). Each station was allocated a specific navigation question, which the test subject was expected to fulfill. The data generated by the test subjects in the seven commuter rail stations, which was recorded and used for evaluation purposes, resulted from positional data, the various velocities of forward movement, as well as head and eye movements (↳Figs. 4a–c).

Juxtaposition of Real Space and Digital Twin (VR Simulation)

Investigated through a comparative analysis was the real space (the subterranean Offenbach Marktplatz Station of the commuter rail) and its virtual twin. It proved possible to evaluate three eye-tracking tests in real space and twelve eye-tracking tests in virtual space. A practical problem was the fact that the virtual spaces were multiple times larger than the space of the laboratory within which the test subjects moved. Piloted and tested therefore were various possibilities of forward movement by means of teleportation. Despite this limitation, it proved possible to gather and evaluate valid eye-tracking and positioning data.[03] Conducted and evaluated as well were qualitative surveys with the assistance of interpretive phenomenological analysis (IPA). The purpose of the survey was to determine whether the VR experience seemed authentic to participants.[04] During testing, all the test subjects became accustomed to the new »reality,« albeit with varying degrees of speed. On the whole, submersion in the virtual

Figs. 5a–f Sequence excerpt: visualization of eye-tracking data in the real Marktplatz Station in Offenbach by means of a film. With the help of eye-tracking glasses, it becomes possible to trace the sequences of use of the test subjects and compare these to the data gathered from the VR simulation. (Source: Design Institute for Mobility and Logistics, HfG Offenbach; Scene Grammar Lab, Goethe University Frankfurt am Main)

station (the immersion quality of the simulation) functioned quite well, although a period of time for acclimatization to the VR world—and finally to transition back to the real world—did prove necessary (↳Figs. 5a–f).

Since most of the everyday tasks and activities performed in a real commuter rail station involve navigation behavior, study participants were assigned corresponding tasks. Typically, the sequence of navigation processes encompasses two activities: wayfinding and path integration. These are based on various human cognitive processes (Coutrot et al. 2018; Wiener et al. 2009). Wayfinding is achieved through the information that is available at key decision-making points within the station, where a choice is made between multiple routes. Path integration is an activity of movement between decision-making points (Mittelstaedt and Mittelstaedt 1980). The investigations focused on wayfinding, since it is of greater relevance to the visual relationships between the objects in the station, and hence for the investigation of the role played by scene grammar in public space (↳Fig. 6).

If scene grammar plays an important role in wayfinding within a station, then the placement of and relationship between the elements of the information and wayfinding system, as well as the spatial objects that are designed to aid orientation, should have a significant influence on wayfinding. Analyses of eye-tracking data support the conclusion that navigational tasks display similar patterns of attention regardless of whether they

03 A virtual reality testbed allows researchers to carry out tests using the cognitive psychology method, involving both software and hardware. The test set-up (observing COVID-19 hygiene requirements) was a virtual reality laboratory measuring 30 square meters, within a larger space (the auditorium of the HfG Offenbach), and included a VIVE Pro eye headset, a high-performance computer, and a server for the Unity database to guide the virtual reality simulation.

04 For the Goethe University in Frankfurt, the IP analysis was conducted by Teresa Schnorbach in the context of a Master's thesis.

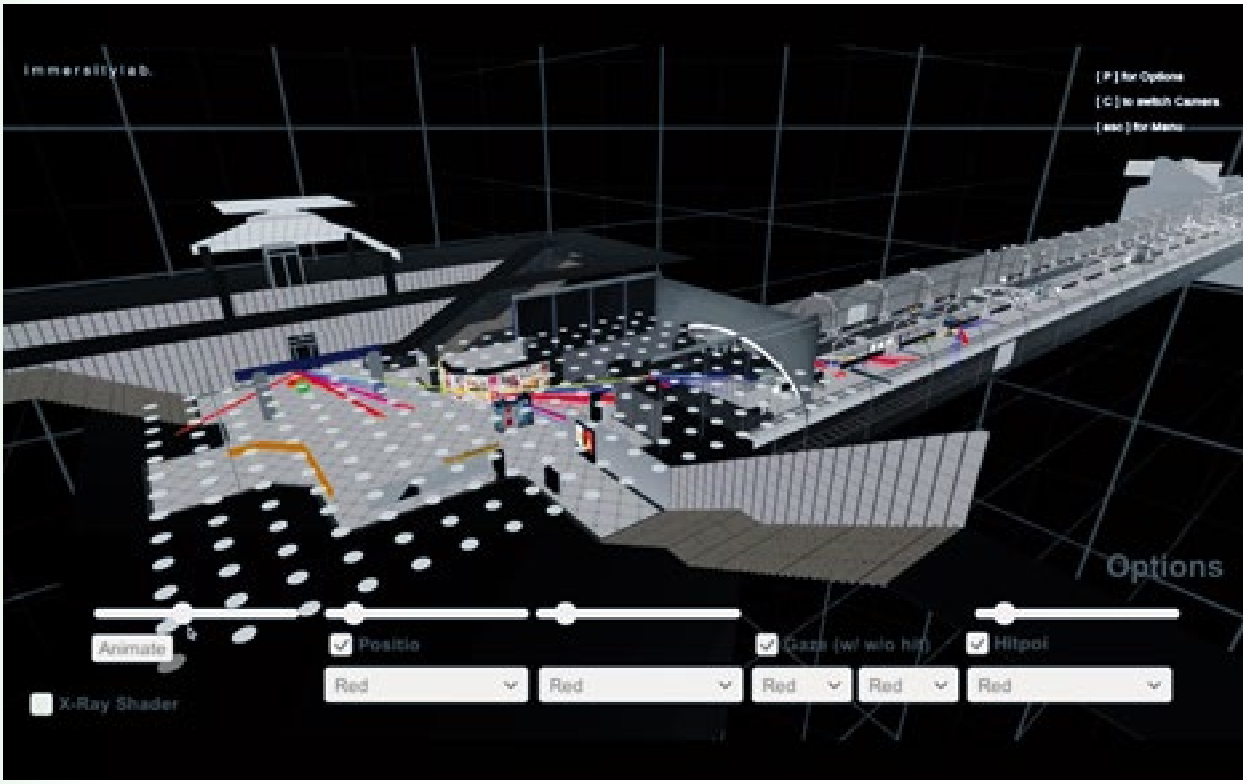
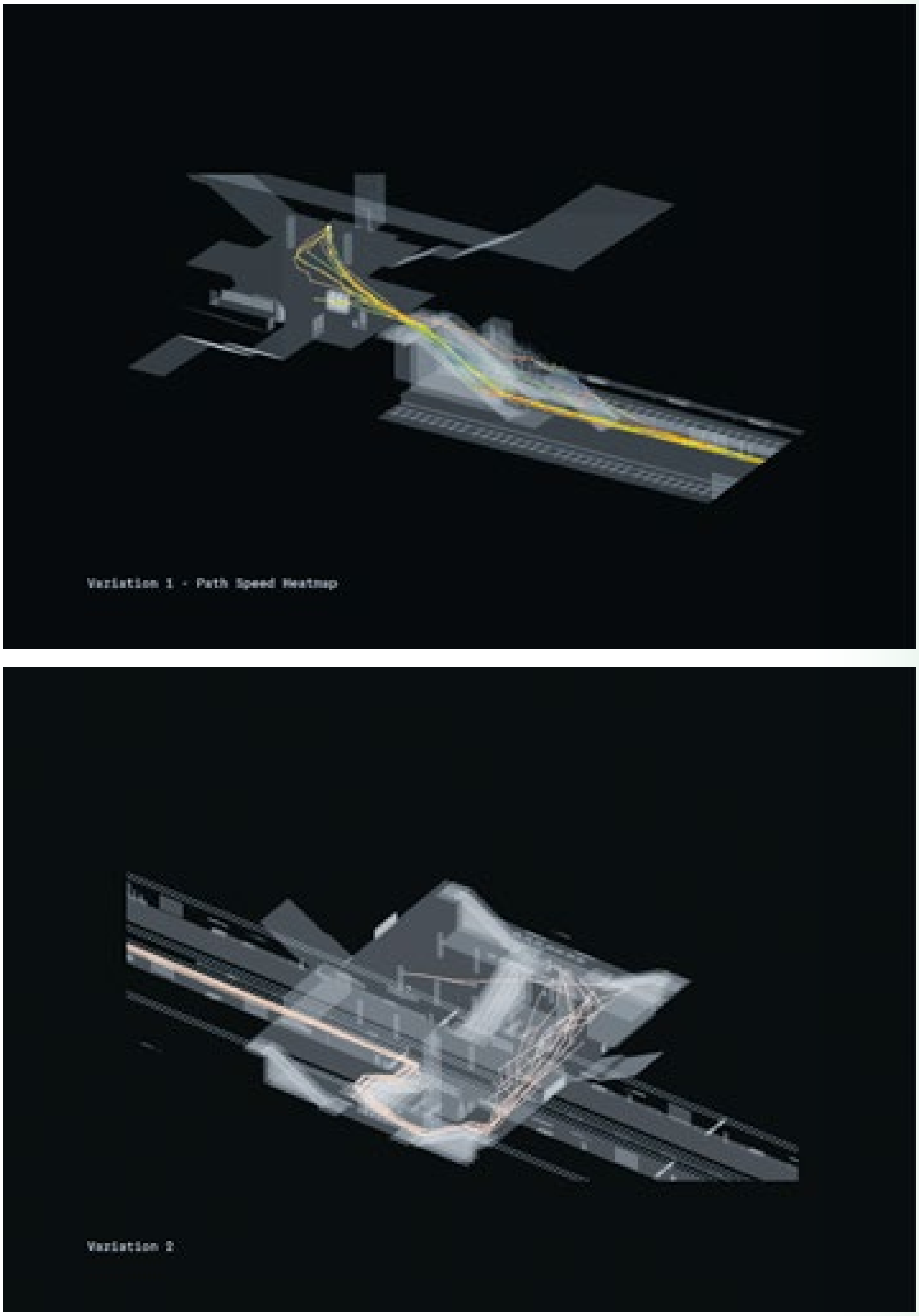


Fig. 6 Eye movements and walking routes can be recorded and evaluated by means of a VR headset. The commuter rail stations are accessible on multiple levels (B levels, subterranean platforms, and staircase crossings). (Source: Ken Rodenwaldt, Design Institute for Mobility and Logistics, HfG Offenbach)

are performed in virtual or real stations. Using measurements based on cognitive psychology and carried out with the help of eye-tracking, patterns of behavior exhibited by the study participants in VR can be juxtaposed with those observed in real spaces. On the basis of a subdivision into wayfinding activities and path integration, certain processes can be precisely defined and compared. The sequencing of search processes is structurally similar in virtual and real space, and corresponding sequences of gazes were observable during attempts at achieving orientation. Clearly, orientation processes proceed similarly in real and simulated spaces. Despite the sequence-altering teleportation processes that take place in digital spaces, both wayfinding processes display similar visual processes of searching and behavior. The comparison highlights the enormous potential of collected eye-tracking data in a spatial situation in the context of mobility and juxtaposes orientation and behavioral processes in both test scenarios (real and simulated) (↳Figs. 7+8).

1. During orientation processes, information elements of the wayfinding systems such as signage are perceived according to the same pattern whether in VR or in real space.
2. During the phase of path integration, which is to say the interval of time after the acquisition of the necessary information and the overcoming of a certain spatial distance, leading to start of the next orientation process, the viewing and movement patterns of test subjects are similar in both VR and real space.

According to the tests conducted, forward movement in VR by means of teleportation—which is to say the overcoming of a large distance through a »leap,« with a corresponding interruption in the flow of movement—had no fundamental influence



Figs. 7a+b The visualization of walking routes can provide information about movement velocity and spatial localization (red = rapid forward movement by means of teleport function = a more limited awareness of the environment). The superimposition of walking routes can also be compared quantitatively. (Source: Ken Rodenwaldt, Design Institute for Mobility and Logistics, HfG Offenbach) on the comparability of the two worlds. In the path integration phase, which is to say in the time that follows the acquisition of the necessary information and the overcoming of a certain spatial distance, leading to the start of the next orientation process, the eye and movement patterns of test subjects were similar, whether in virtual and real space. This can be concluded as well from the in-depth qualitative interviews. One individual who was quite familiar with the Offenbach Marktplatz Station stated emphatically that when navigating in the digital VR twin, she fully imagined herself to be in the real station. While moving from one space to the next, she found herself scanning her surroundings, searching out all of the features that were familiar to her from the real station.

Based on qualitative interviews, it was concluded that the degree of reality of a VR simulation needed to be different depending upon the question under investigation: while during the process of orientation, the primary attention was directed toward the continuity and recognizability of the key elements of the information and wayfinding systems (the focus of attention was on signage with information in the form of images or text, while the surroundings receded into the background), objects in space that were not of primary relevance for orientation seemed to play a more important role with path integration. The focus of perception was no longer on the orientation system, and perception was directed toward objects in the surroundings (with the gaze sweeping widely). Important here is a heightened degree of reality of the VR simulation since the aesthetic qualities of the space shape experience now in essential ways.

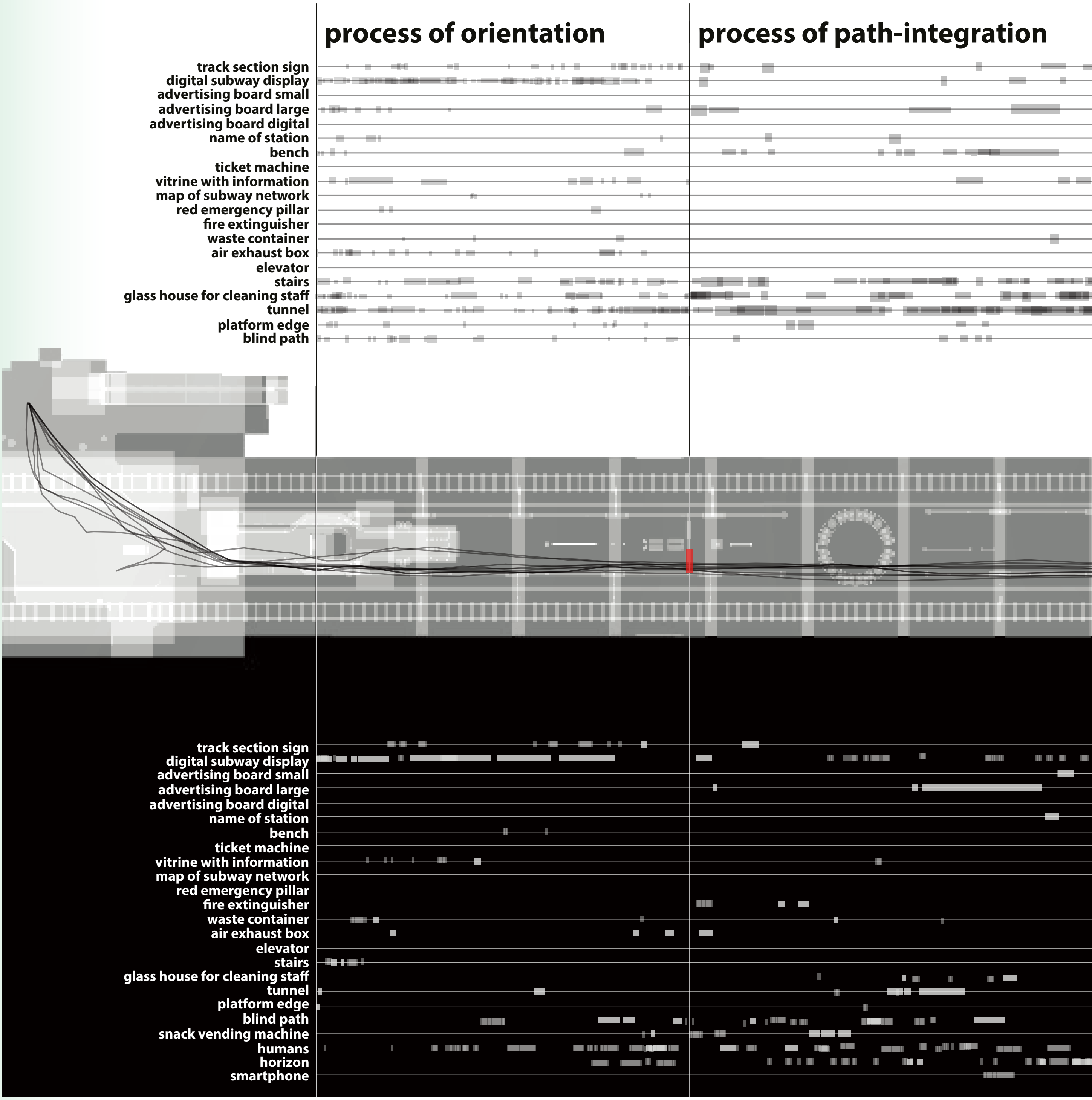
Spatial Orientation and the Influence of Design on Navigation Behavior

The IPA interviews showed that the study participants used the information and wayfinding system primarily to perform navigation tasks. Meanwhile, additional spatial orientation elements, for example, staircases and exits (spatial openings) had an influence on successful navigation in space. In this context, the formal-aesthetic analysis based on product language supplied important references with regard to the influence of the structure of the spatial environment, including the weighting of orienting elements (concision and distribution in space, the overall density of orientation information, and how that works in relationship to other forms of information not designed to aid orientation). It was not yet possible to fully capture the orienting function of spatial elements. For this reason, there was recourse to the concept of »mental maps,« developed in the field of architectural and planning theory, with their guiding elements designed to structure spatial orientation (Lynch 1960). This refers to the quality of the formal structure of urban space, but also examines interactions between moving users and the built environment in order to identify elements (cognitive map) that are relevant and cognitively effective for orientation (Vöckler 2021). The two components »landmark« and »path« are empirically significant for mental representations and current navigation as they have a high degree of functional meaning and allow little leeway for individual interpretations (Guski and Blöbaum 2008). Particularly relevant to the project's investigative approach was the element »landmark,« which was operationalized here mainly in its function as an incisive optical reference point, one that plays a central role in spatial orientation, and on which users recognizably rely to an increasing degree as soon as a spatial situation becomes more familiar. The identity-forming aspect of landmarks, which often have a symbolic significance in the urban context (historically significant buildings, for example), and their corresponding importance in the memory of spatial situations (mental maps), were factored out. The focus was on the process of wayfinding, which cannot be captured through the evaluation of a schematic or static mental map. Environments are complex entities and are registered and assessed through the goal-directed activities of sequentially structured interactions with the surroundings, as further differentiated in design research into the landmark concept (Arthur and Passini 1992; Vinson 1999; Farr et al. 2012). As analyses of eye movements and fixation points have shown, elements of spatial orientation, including highly visible objects that structure the space such as columns or freestanding ticket vending machines, serve as optical points of reference that supplement the information elements of the navigation guidance system. Then there are elements such as staircases and spatial openings (entrances, exits), which are of importance for a target-oriented wayfinding, and are not only optically incisive, but also represent decisive spatial offerings for successful spatial navigation (in product language: the indicating functions; reflected on as affordance in terms of design theory; see Norman 1988). The lighting elements, the positioning of other elements of spatial orientation and their visibility, the spatial structure, its visual fields, and the recognizability of elements all make a major contribution to successful wayfinding, and were taken into account in the formation of variants in VR. The importance of the formal-aesthetic spatial structure (ordered complexity) in the act of perception, as reflected to date in the theory of product language only with regard to objects, was also investigated spatially, with due consideration given to the relevant theoretical findings from the fields of architecture and design theory. The focus was on elements that were essential for orientation, as well as their visibility and conspicuousness.

Objects that facilitated orientation—the information elements of the wayfinding system (maps, signage with graphic symbol such as arrows and lettering) and landmarks that serve as optically incisive spatial points of reference (ticket vending machines, columns, staircases, exits, and entrances)—were manipulated within the experiment. Through the formation of diverse variants of the spatial situation, the information and guidance system and the landmarks could be juxtaposed, and their relative importance for the orientation process tested for high contrast and low contrast variables. Factors that influenced attention (distraction, guidance), cognition (orientation, understanding, memory), and emotion (sense of well-being) were investigated and assessed. Navigation relied primarily on the information and guidance systems but the landmarks were also very important in the VR simulations. According to statements by the test subjects, they appeared to define the spatial context in its materiality, which corresponds to the landmarks' function as essential elements of a cognitively processed image of the surroundings, as confirmed by both design research and environmental psychology. They convey the sense to participants that they are dealing with real experience with and in a station. The function of the landmarks (as optically incisive points of reference or markers) resembles the function of anchor objects in the theory of scene grammar (Võ et al. 2019; Võ 2021). Anchor objects are for the most part large and static (i.e., washbasins), which predict the identity and location of other smaller objects (hand soap is generally found *on* a washbasin, a towel *alongside* it), and which constitute a spatial context. Anchor objects therefore play a decisive role in the efficient search for objects in space (Boettcher et al. 2018; Helbing et al. 2022). The spatial context that forms the commuter rail station, for example, is defined by the subjects, and elicits certain behavioral and interaction processes in test subjects. The corresponding object constellations that form landmarks, the spatial-material elements of the architectural fabric; and the information elements that form the wayfinding system, with its images and texts on signage, columns, etc. make localization possible in familiar situations. Their design, in particular through the interplay of the two, contributes in essential ways to successful navigation through spatially complex contexts such as a multileveled commuter rail station, and evidently, generates trust as it ensures an understanding of the spatial situation.

Summary and Outlook

The comparative investigation of a real space together with its virtual twin has demonstrated that the simulation taking place in virtual reality is a well-adapted instrument for researching and recording human experience and movement behavior in a mobility space. Virtual reality can convey alterations to the design of given space, together with its objects and information sources at a low threshold and with a high degree of authenticity (immersive quality). The evaluated results supplied vital information concerning


process of orientation
process of path-integration
track section sign
digital subway display
advertising board small
advertising board large
advertising board digital
name of station
bench
ticket machine
vitrine with information
map of subway network
red emergency pillar
fire extinguisher
waste container
air exhaust box
elevator
stairs
glass house for cleaning staff
tunnel
platform edge
blind path
track section sign
digital subway display
advertising board small
advertising board large
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blind path
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humans
horizon
smartphone

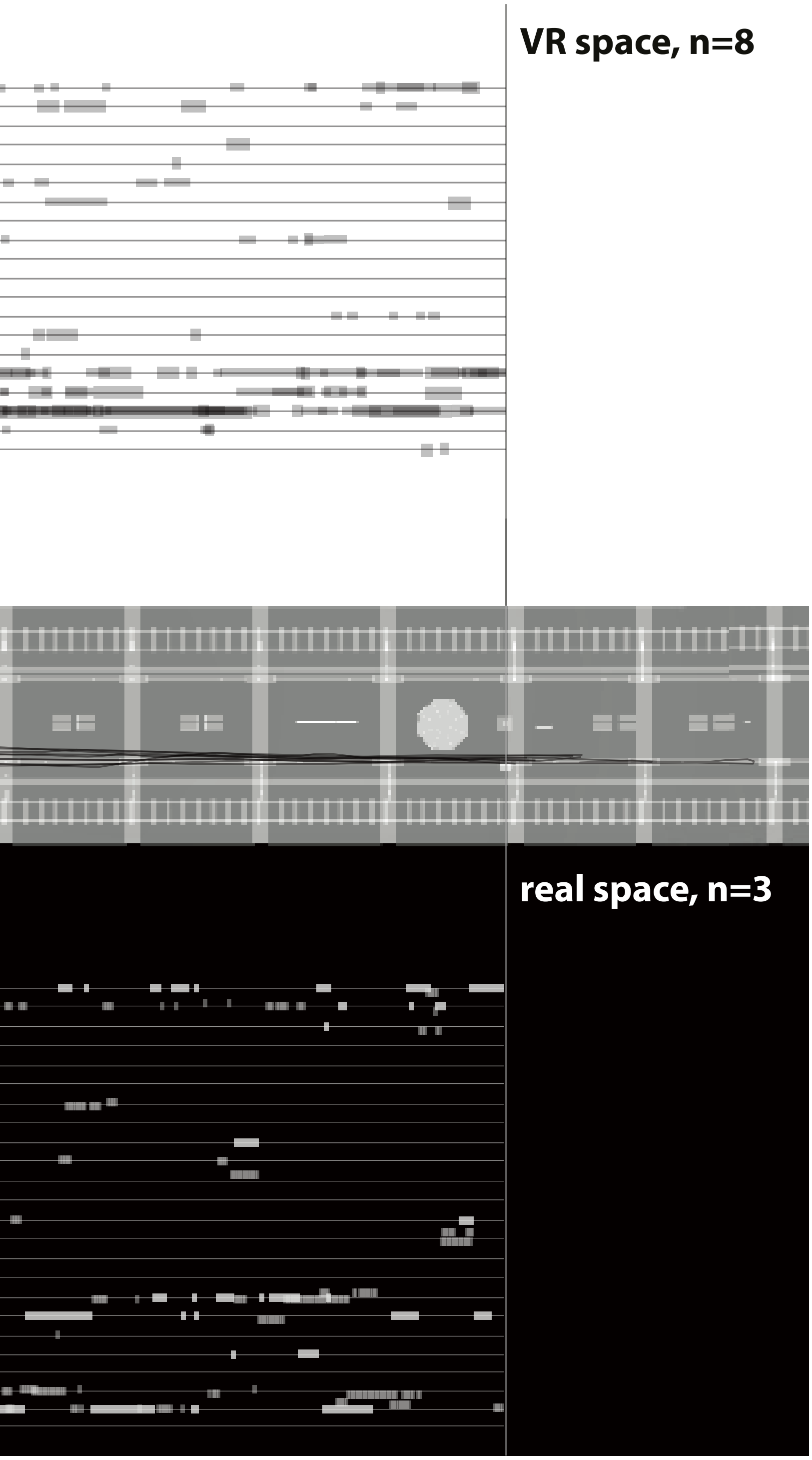

Fig. 8 Comparison of the eye-tracking data collected in VR and in real space. The layout of the platform area of the Offenbach Marktplatz commuter rail station and the B level of the station (eastern entrance), visible at the center, display (as lines) eight of the walking routes covered by the test subjects during the VR experiment. The evaluation shows which objects were viewed by the test subjects during the wayfinding process, and in which area of the station. The data positioned above the layout (black lettering on a white background) shows the objects that were perceived in virtual reality. Depicted below the layout (white lettering on a black background) are the objects that were viewed during the experiment, conducted in the real station. (Source: Julian Schwarze, Design Institute for Mobility and Logistics, HfG Offenbach)

which characteristics of the simulated space can be measured during goal-directed movement behavior in the test situation and what degree of realism is advisable for a given simulation with respect to the given sequence of interactions. The results also demonstrate that design modifications can be tested effectively in virtual reality. This has meant the development of important groundwork for subsequent research. Moreover, the project has generated large-scale research data that has yet to be fully evaluated, while developing and successfully implementing an interdisciplinary research approach.

It has been shown that eye-tracking in virtual reality allows us to measure with precision which objects are viewed, for how long, how often, and at which locations. The correlation of measurement data with interpretive-phenomenological interviews yields reliable results concerning the impact of design measures. In virtual reality, design elements such as lighting, surface quality, color, object positioning, and object form, along with spatial structure, can be varied and tested in targeted ways. A limitation of such simulations, it must be conceded, is that they are able to reproduce social interactions, imparted via avatars, only to a limited degree (they were not taken into account in the test set up). The limitations of the test capabilities are also evident when it comes to aesthetic effects: with the current state of technology, atmospheric impressions caused by bodily sensations in spatial situations are not attainable.

The test area was restricted to the navigation of a public mobility space, and hence to goal-directed action (with intentionally oriented attention). Foregrounded here, correspondingly, were the functional demands on design, on the ways in which information, object positioning, and spatial structure can be used to facilitate and improve orientation, and hence wayfinding. Subsequent research will go beyond functional demands to incorporate the emotional impact of design (for example, a sense of well-being or a subjective sense of security) with greater emphasis.[05]

The findings of the psychology of perception and cognition are of considerable interest for design research, allowing well-founded, quantitative evaluations of the influence of design decisions on perception and the assessment of spatial situations. At the same time, the formal-analytical model of product language represented a point of connection with the analytical approach of scene grammar. The rules of scene grammar, produced by abstracting from spatial interactions, as well as the operationalization of anchor objects, constituted an important foundation for the research project. This approach was extended through the integration of findings from architectural and design theory with regard to the investigation of spatial processes but will need to be illuminated in greater detail in the future, in particular with regard to their referential and offer functions (indications/affordances) and their symbolic meaning (product semantics). The methods of scene grammar are well suited to the investigation of wayfinding in mobility spaces and can be quite productively linked with the research methodology of design studies. This makes possible valid statements concerning the impact of individual design parameters. This does not replace the design process, the concrete design, but does provide designers with important references concerning the potential impact of a variety of design parameters, depending on the location's framework conditions and user intentions. Research carried out to date was able to determine that a systematic examination of design parameters is possible in virtual reality, even though the areas of investigation need to be differentiated further, and moreover examined with an eye toward their ecological validity.

Virtual reality simulations have a high application potential, and not just in interdisciplinary basic research. In the context of transportation infrastructure measures, they allow planners and designers to gather feedback from users during the initial planning stages, thereby qualifying the design. Moreover, they can be highly effective in communication terms, since they are able to convey the quality of the design with a high degree of credibility to clients, decision-makers, or the users; conversely, they can also be useful in avoiding planning mistakes. In this context, the degree of realism is of great significance, for it vouches for the »credibility« of the design, for in the end, after all, the quality of the planning and design is essential. The results presented here represent a contribution to making human-centered design and planning possible in planning processes through the application of virtual reality technology.

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Serious Games and Gamification to Support Environmentally Friendly Mobility Behavior

Stefan Göbel,
Thomas Tregel,
Philipp Müller, and
Ralf Steinmetz

Fig. 1 Serious games approach: Serious games combine game concepts and game technologies with further technologies and concepts in an interdisciplinary context to be applied in a broad spectrum of areas. (Source: Stefan Göbel, TU Darmstadt, 2021)

Motivation: Nowadays, climate, energy, security, mobility, health, and education represent publicly relevant topics, both for the wealth of individuals and society. The Fridays for Future activities (Wikipedia 2022) address ongoing climate change and underline the strong need to change mobility behavior (Hunecke et al. 2010), especially the switch from private car usage toward more environmentally friendly modalities (Nordlund and Garvill 2003). Hereby, an ongoing trend is noticeable—primarily in the younger generation [the Fridays for Future has been initiated by fifteen-year-old Greta Thunberg among others, (Crouch 2018)]—to prioritize using multimodal and intermodal mobility options (a route from a point A to a point B might be achieved by walking to a bus station, using public transport, utilizing a park-and-ride, using pedelecs, etc.) rather than understanding the car as both status symbol and the one and only means of transportation, as in former times (Ritz et al. 2014).

Game-Based Approach: A serious game is a digital game that was created with the intention to entertain and achieve at least one additional goal (for example, advancement in education or health). These additional goals are called *characterizing goals* (Dörner et al. 2016). Application examples of serious games include, but are not limited to educational games for younger audiences; vocational-training and corporate-training games and simulation applications in the educational sector; cognitive training and exergames (for example, balance or cardio-training) for prevention and rehabilitation in the health(care) arena; and marketing games and awareness-and-social-impact games for socially relevant topics such as security and climate (↳Fig. 1).

Similar to serious games, *gamification* (Deterding et al. 2011, Walz and Deterding 2015) uses game-based concepts in nongame context. The difference is that gamification typically is used on top of existing applications (for example, e-learning applications or knowledge management systems) and do not represent complete games. Gamification elements basically include points, badges, and leaderboards.

Idea: Considering the need for innovative concepts to support environmentally friendly mobility behavior on one side, and the potential of serious games and gamification on the other, the simple idea is to use gamification and serious games concepts as motivational instruments to support environmentally friendly mobility behavior in a game-based, playful manner.

For that, the Serious Games group at TU Darmstadt analyzed existing approaches and has elaborated the concept of sliced serious games.

Related Work

Apart from the development of an inspiring mobility app with a fair scoring mechanism and appealing content, research aspects include the sensor-based activity recognition of transport means (modalities) and gesture recognition of physical exercises, both via (one) smartphone (only).

From an application-oriented perspective, the topic of game-based approaches to support environmentally friendly mobility approaches has been addressed for a couple of years, included in projects funded by the European Commission, such as SUPERHUB in 7th Framework Programme (FP7),[01] 2011–2014, which provides a solution through an app for people to plan and choose the best possible ecofriendly means of mobility to reach a destination. The showcase of ViaggiaRovereto (Kazhamiakin et al. 2015) shows that taking a playful approach toward a mobility behavior change works. Within an experimental study over five weeks, users were invited to use a mobility app. In the first week the users became familiar with the app while information about their mobility behavior was collected on the system side to have as a baseline. In the subsequent two weeks, intermodal mobility chains were suggested, including transport modalities via car, train, bike sharing, bicycling, and moving on foot. The suggested mobility chains (routes) were ranked and presented to the user according to ecological guidelines (basically based on carbon dioxide emissions). In the final two weeks of the study, participants were introduced to the game Green Game con ViaggiaRovereto, which includes Green Points for environmentally friendly intermodal mobility chains, Health Points for distances traversed by foot or by bicycle, and Park&Ride points when those services have been selected. Further, gamification elements such as awards in the form of badges, trophies, and leaderboards were integrated. At the end of the experimental study, all participants received a certificate listing all received points and rewards. Additionally, as an incentive, the three most successful participants received a voucher for one-month's free service awarded by a bike sharing provider.

The experimental study showed two outcomes. First, the mobility app was used much more frequently during the gaming phase. Second, the experiment proved a positive mobility behavior change during the gaming phase: in the first week 49 percent of participants used cars, while during the gaming phase during the last two weeks of the experiment, that fell to only 21 percent.

Technology-wise, mobile activity recognition is a well-researched topic that covers the differentiation between activities such as standing still, walking, running, or being in a vehicle based on a mobile device's sensor data. A generic version of activity recognition is already available as an official Android API.[02] Other forms of activity recognition exist that cover context-specific activities such as military or fitness activities (Lara and Labrador 2013) rather than generic activities.

Sliced Serious Games

The concept of *sliced serious games* has been introduced by Göbel et al. (2017). ↳Fig. 2 illustrates the working principle and scenarios of sliced serious games. The overall aim of the approach is to support and motivate for environmentally friendly mobility behavior. From an analog perspective, this serious aspect is the characterizing goal of the sliced serious game and determines the functionality of intermodal mobility assistants (which modalities should be considered, in which priority) and provides the basic conceptual information for the design of the game world. From a global, societal perspective, the game approach is successful when it is proven that many individuals change their mobility behavior and switch away from car use, resulting in a reduction of carbon dioxide emissions.

In principle it is not necessary to play games. Users might use a mobility assistant to select environmentally friendly routes from a geographic location A (departure) to a destination B; the system recognizes the activities (as a basis to prove the effects) and provides good scores as rewards for choosing environmentally friendly modalities. This scenario might be interpreted as the »gamification version,« as seen in the upper layer in ↳Fig. 2.

In contrast, a second scenario focuses on the use of games and sliced mini games, resulting in a real

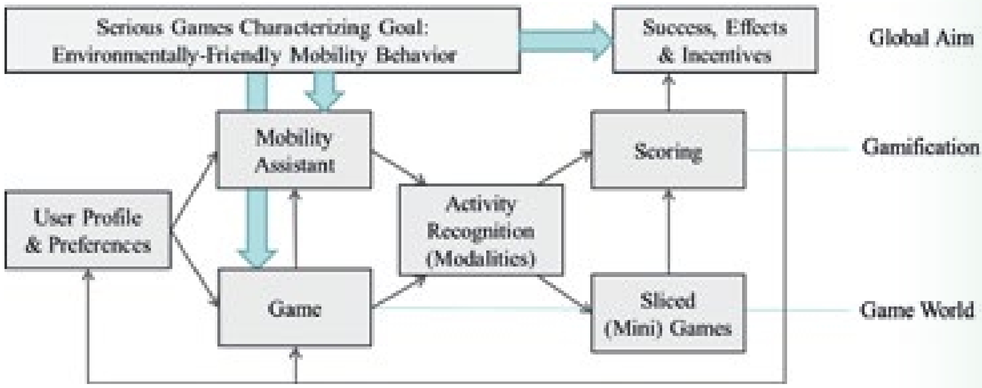

Fig. 2 Conceptual framework for sliced serious games: The illustration shows the individual components and major aspects of a sliced serious game framework. (Source: Stefan Göbel, TU Darmstadt)

»game version.« Here, users optionally use a mobility assistant, but the difference is that they start with a game and always come back to the game world during their intermodal mobility trips. As an incentive, they get an additional score for the game activities—in addition to the score for intermodal mobility activities—enabling new functionality or further content (that is, up-leveling) in the game world.

In both scenarios, further nongaming incentives, such as reduced-price models for public transport, might be considered by mobility service providers; they are already under discussion in townships such as Darmstadt as a regulatory component of public transport (systems) (↳Fig. 2).

Components of a Sliced Serious Games Framework

User profile and preferences. User profiles and preferences serve as the administration and configuration components for the framework. User profile information includes personal information such as age and gender, but also gaming information and preferences on mobility behavior. Gaming information describes: (i) the experience in gaming, identified using categories such as »casual,« »regular,« and »hardcore« gamer; (ii) preferences on game genres, such as »strategy,« »adventure,« and »action« games; and (iii) player type information according to player models from Bartle (1996) or Houlette (2004). Referring to preferences on mobility behavior, basic information includes the motivation and purpose/necessity for mobility resulting in categories of user groups such as pupils (going to school), commuters (students or employees on their way to work); and seniors (visiting a doctor, shopping, or visiting a cultural event). User preferences are composed by using typical factors such costs and time, but also by considering psychological factors such as autonomy, arousal, status, and privacy as well sociodemographic factors such as income and household size (Hunecke et al. 2010). The user profile information and preferences are used both for the configuration of the mobility assistant (modus and style, meaning its visual appearance and the extent of provided information/information load) and the game world (game genre, gameplay, content and, again, user interface design).

01 https://ec.europa.eu/digital-single-market/en/content/superhub-tailor-made-mobility (accessed on February 4, 2022).
02 https://developers.google.com/location-context/activity-recognition/> (accessed on February 4, 2022).

Mobility assistance. Recently, there are more and more mobility assistants, including both traditional portals about public transport routes and schedules and mobility apps (Digmayer et al. 2015) providing both individual mobility services such as car sharing or bicycle rental and integrated services covering the provision of different mobility services, such as vielmobil.de (for the Rhein-Main region around Frankfurt in Germany) or the Intermodal Mobility Assistant (IMA) (Masuch et al. 2013). The goal of IMA is to provide an open platform where mobility service providers can integrate their offering/service in a standardized way. The working principle of integrated mobility services/platforms such as IMA is divided into three steps (↳Fig. 2): (1) the user (optional) provides individual mobility preferences and (mandatory) defines a route with a starting point and destination plus date/time; (2) the system figures out possible connections in a route search phase and presents a list of possible routes/intermodal mobility chains, considering user preferences as basis for the ranking/listing of possible routes; and then (3) the user chooses a route from the list. During travel, adaptations might be necessary according to traffic, public transport delays, etc. These changes are automatically considered by the system (using real-time information from mobility service providers) and presented to the user.

*Activity recognition***.** This component aims to figure out which movement modalities are used by the users. For that, activity sensors are necessary. The main challenge is to distinguish between modalities such as »in a bus,« »in a car,« or »in a tram.« Some libraries such as Google's Fence API,[03] as part of Google's Awareness API developed for Android in 2016, offer an open interface for activity recognition. This API delivers information about the geographic location of a user, headphone status, modality types, and the weather. Referring to the movement modalities, the states »IN_VEHICLE,« »ON_BIKE,« »ON_FOOT« (as an aggregation of walking and running), »WALKING,« »RUNNING,« »STILL,« and »TILTING« (is set when the smartphone orientation changes significantly) are recognized. If it is not clear, the modality is set as »UNKNOWN.« The API works very well for modality changes, but the recognition accuracy rate of only about 70 percent could be improved.

Further technical information about activity recognition in game-based approaches to support environmentally friendly mobility behavior is presented in Reitmaier et al. 2022, in this book.

*Scoring***.** When developing scoring mechanisms, the determination is which ones are appropriate to motivate users and to reasonably reflect their mobility behavior. They need to provide a »fair« rewards system for the use of (more or less) environmentally friendly mobility behavior. Scores reflect both the choice of movement modality and the duration of an activity per »slice« of an intermodal mobility chain. Furthermore, while playing the games is also rewarded with points, activity points have more weight compared to game points. That means a user who prioritizes environmentally friendly movement modalities but is not playing the games gets a higher score than a user who is playing but does not show environmentally friendly mobility behavior. A user doing both—that is, environmentally friendly mobility behavior and playing the game (when possible)—has the best chance to become top of a leaderboard for environmentally friendly mobility behavior.

*Effects***.** The ViaggiaRovereto application prototype (Kazhamiakin et al. 2015) might serve as a best-practice example validating the concepts of a gamified framework for environmentally friendly mobility behavior. As described above, the effects of the experimental study have been impressive: car use decreased from 49 percent to 21 percent in the gaming phase of the study. Contrary to »soft« empirical evaluation studies based on questionnaires and interviews, the results have been extracted based on quantified, technology-supported recorded data. Certainly, further mid- and long-term studies measuring changes in mobility behavior are required in application examples such as ViaggiaRovereto in order to derive sound scientific statements about the practical effects of game-based approaches for environmentally friendly mobility behavior.

Game Structure: »Sliced« Approach

An open question remains how to structure a (mobile) game world and particular »sliced« mini games considering the nature of intermodal mobility chains and short timeframes in which to play.

Most mobile games are used as casual games with a typical play time of five to ten minutes (Lee 2014). As such, a user should be able to have a complete mobile gaming experience, with the expectation of achieving a concrete task (goal of a game), in this timeframe. Scolastici and Nolte (2013) suggest that this time should be even shorter, that is, a maximum of three minutes. Due to the short time span, it is almost impossible to achieve an experience of immersion and »flow« (Csikszentmihalyi 2000). Instead, mobile games should be flexible and easy to access (utilizing the »dip-in-dip-out« principle with an easy start and finish), and easy to play (gameplay, game mechanics). Referring to the narrative aspect, Flintham et al. (2007) suggest structuring the underlying story of mobile games into episodes. Popular games following that episodic structure include the Facebook game CastleVille by Zynga. The episodic structure means the game is not limited to a fixed story, but is extendible through additional episodes with new content, which not only lengthens the time of play, but also motivates a user to revisit the game (again and again) and to explore the new content. Lee also suggests subdividing stories for mobile games into small parts, or »thin slices.« In the same context, Buchanan (2014) introduced the concept of byte-sized storytelling, also following the »dip-in-dip-out« principle. Practically, story/game episodes in the form of game slices might be interpreted as game modules that can be arranged in any order. For the orchestration of game slices (mini games) within intermodal mobility chains, the (external) time constraints of route sections (and movement modalities) as well as the appropriateness of mini games (and its gameplay and game control) for particular movement modalities need to be considered. The question is which episode/mini game fits best for a modality in a specific moment and which next episode/game module should be selected? In that context, Göbel et al. provided an algorithm considering external and internal constraints in their paper about story pacing (Göbel et al. 2006) and elsewhere provided prototypical implementations of the sliced serious games concept (Göbel et al. 2019).

Summary

Serious games and gamification represent promising approaches to support environmentally friendly mobility behavior in a playful manner. This article has provided a theoretical framework to better understand the concept of sliced serious games with its crucial elements and possible outcomes in supporting green mobility modes. Whereas the focus of initial prototypes was on gaming aspects, the focus shifted to awareness and learning aspects in the form of educational game environments with implicit learning about the effects of transport modalities in terms of energy, that is, carbon dioxide emissions. Hence, the characterizing goals (see understanding and main characteristics of serious games, Dörner et al. 2016) of those approaches are two-fold: (1) awareness and learning about mobility behavior and its energy effects is envisioned, and (2) users should be inspired to change their own mobility behavior. The target user group addresses not just the younger audience, but all smartphone users.

03 https://developers.google.com/awareness/android-api/fence-api-overview> (accessed on February 4, 2022).

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Playful Incentives for Sustainable Intermodal Mobility in the Mobile, User-Centered Application FlowMo

Sabine Reitmaier, Philipp Müller, Nicole Reinfeld, Thomas Tregel, Andrea Krajewski, Petra Schäfer, and Stefan Göbel

Through the dissemination of mobile devices such as smart phones, tablets, and smart watches, as well as the further development of built-in sensor technology, mobile applications (apps) are taken for granted by many people as a part of everyday life. Alongside mobile games developed for entertainment purposes, many apps use game-typical elements such as progress indicators, rankings, and challenges to heighten motivation for continued use. This concept, referred to as gamification, is being used with increasing frequency for apps that are designed to encourage a specific activity or behavior, such as learning a language or regular physical training. In addition, mobile applications include so-called serious games, where the objective includes both entertainment and at least one other goal, also called characterizing goal (see Göbel et al. in this volume).

In the context of interdisciplinary mobility design, personalized applications make it possible for mobility users to experience the potential impact of their own mobility behavior on the environment and the climate. They can also convey information with a greater sense of immediacy, thereby heightening an awareness of responsibility for the consequences of one's own actions. In addition, mobile applications offer the possibility to directly inform users on the move about their current mobility behavior and thus encourage them to behave in an environmentally conscious manner.

Background, Challenges, and Aims

When it comes to the overarching goal of motivating users through playful incentives (gamification and serious game elements) to engage in climate-neutral mobility behavior, one question necessarily arises: how should such an application be designed, both technologically and thematically? To investigate this question, a user-centered development of such a mobile application was planned based on a preliminary concept.[01] Here, the challenges can be subdivided into the categories of functionality and user acceptance.

Functional challenges include the technical implementation of mobility recognition, which should accurately register and represent the user's mobility behavior, as some modes of transport are difficult to distinguish from one another. By means of the built-in sensor technology found in mobile devices, one area of current research, therefore, deals with the challenge of distinguishing between transport modes with similar road behavior, i.e., automobiles and buses, something that is not possible with current applications. For a close connection between game content and mobility recognition, it is also important that this function works in real time, and that temporary errors such as the unstable recognition of two differing modes of transport be avoided, since this can be highly detrimental to the gaming experience. Given these challenges, the focus of research to date has been on linking game content to distinctive real-world

01 The preliminary concept for the application FlowMo was formulated at the Multimedia Communications Lab of the TU Darmstadt. Designers from the HfG Offenbach took charge of extensions related to user-oriented requirements, generated rough and fine concepts, and planned out the design implementation. Together with transportation planners from the specialist group Neue Mobilität (ReLUT) at the Frankfurt University of Applied Sciences, they supervised the development process, which involved ongoing user surveys and evaluations. Participating in the project were: Sabine Reitmaier, Philipp Müller, Nicole Reinfeld, Andrea Krajewski, Andreas Gilbert, Carola Klingbeil, Silvio Lepsy, Sarah Lerch, Felix Reinhold, Thomas Tregel, Stefan Göbel, Peter Eckart, and Petra Schäfer. The project is part of the research focus "Infrastructure—Design—Society," which received support from 2018 to 2021 from the Landes-Offensive zur Entwicklung wissenschaftlich-ökonomischer Exzellenz (Statewide Campaign for the Development of Scientific and Economic Excellence, LOEWE) of the German Federal State of Hesse. The project partners were the University of Art and Design Offenbach (design, management), the Frankfurt University of Applied Sciences (transportation planning), the Goethe University Frankfurt (mobility research), and the Technical University Darmstadt (media and communications technology/architecture).

locations (Göbel et al. 2019) so that it is exclusively the position of the player that is of relevance; these are referred to as »location-based games.« However, if the gaming content is adapted to specific active locations rather than the player' mobility behavior, it could mean that no game content is available while they are using public transport.

In contrast, the concrete objective of the prototype concept is that gaming content should be made available during the use of public transport and should be adapted to the player's current mobility behavior. This becomes possible through the continued development of mobility recognition, which permits a more accurate real-time identification of the current mode of transport through the application of machine learning methods and the integration of public transport maps (in detail, see Tregel 2020).

Among the challenges regarding acceptance by users are the following questions: Will potential users accept the tracking of their mobility behavior that results from the use of mobility recognition? If so, under which circumstances? Which play elements and genres do users expect to find in such mobile applications? How closely should these be linked with the player's individual mobility behavior? Do potential users expect additional options and features that are designed to encourage regular use of the app?

Process and Methodological Approach

User-centered development proceeded along a step-by-step process, which included user research, conception, interaction design, and visual design. The process was iteratively accompanied by methods. The methods used were

- User surveys with online questionnaire and with interview guidelines
- Prototyping with interactive click dummies in low- and high-fidelity
- Prototyping with a drawn digital storyboard (Hanington and Martin 2019: 176–177)
- Critiques in the form regular internal team reviews (Hanington and Martin 2019: 66–67)

The preliminary concept served as the basis for an online survey. It consisted of the requirements of technical functionality (self-measurement settings; mobility behavior tracking), and a characterization of the game concept in two variants (mini games, eco app). The results of the online survey led to the visualization of a rough concept, which was formulated as a storyboard. The storyboard showed the use of a roughly sketched application in various scenarios from the users' point of view and was used in a subsequent survey with an interview guide. Both user surveys were conducted with the help of a long-term focus group (on the long-term focus group as a method in mobility research, see Schäfer et al. in this volume). The 232 focus group participants were recruited in 2018 through an online survey that was advertised and transmitted via various channels (↳Fig. 1).

Results

The results of the first survey of the focus group were evaluated both textually and graphically and processed for further communication. The following were striking: a fundamentally positive attitude toward self-quantification, a general interest in a graphic, informative representation of one's own mobility behavior, interest in already familiar minigames (such as Candy Crush) and the lack of a pronounced affinity for games among the group of participants.

The second survey was realized with the help of an online videoconferencing tool and was recorded in image and sound, transcribed, and formulated into design-specific derivations in the dimensions of tracking, game genres, game situations, self-measurement, conceivable statistics, challenges, and the design of the scoring system. This concerned, for example, the possibilities to visualize one's own mobility behavior, to be able to compete with oneself and others through challenges, an expansion of the points award system to all areas of the application as well as the possibility to equip a game character with items.

The resulting detailed concept consisted of a self-measurement component that registers and depicts user behavior while rewarding environmentally friendly behavior; and a game component

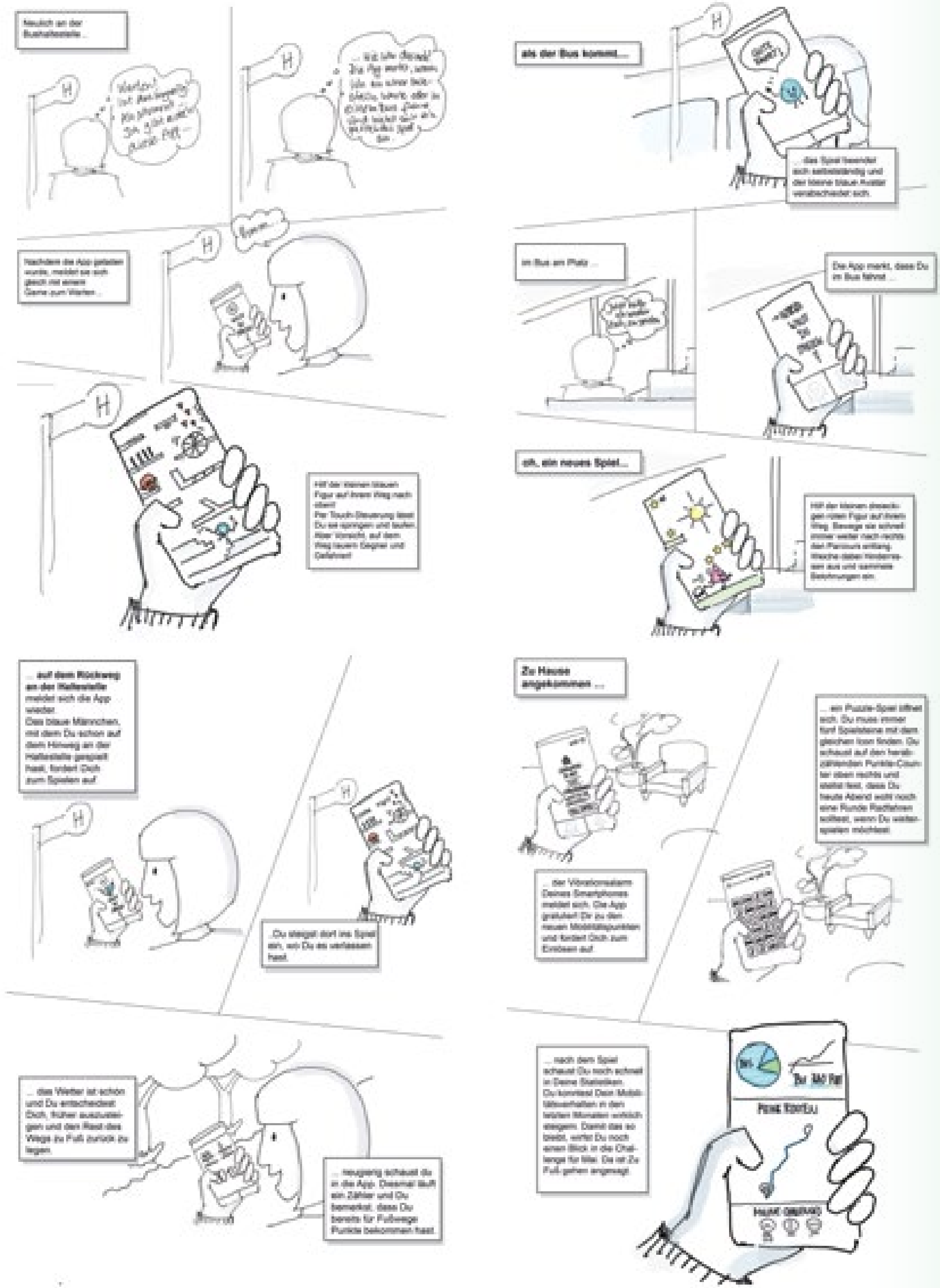


Fig. 1 Rough concept as storyboard with user scenarios (Source: Andrea Krajewski)

in which players assist a main character to purify the air and to maintain its purity through environmentally aware mobility behavior (↳Figs. 2+3).

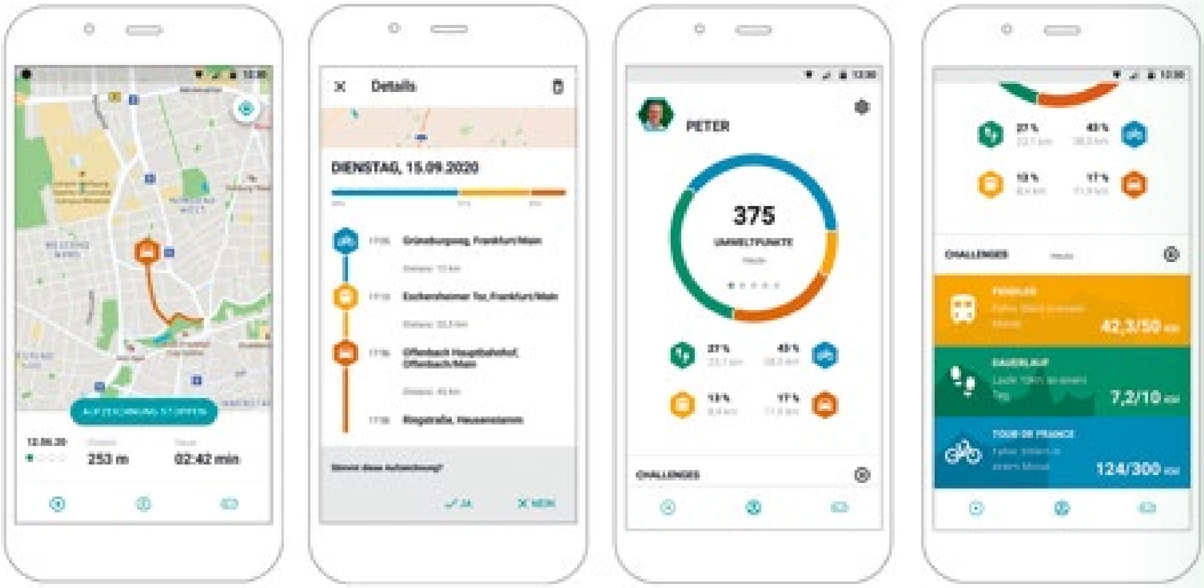
The game character Florin the Molecule becomes the narrative accompaniment and primary figure of the application. He is emblematic of the narrative, according to which the mobility behavior of each individual has an influence on air pollution caused by harmful substances that are dispersed through motorized individual transport. The application begins with a greeting by Florin, a fictive molecule that is able to collect pollutants. Users create a profile that serves as a basis for evaluating and localizing individual application data and are able to register routes and evaluate them subsequently. The user's location and mode of transport determine whether two different minigames are active and whether environmental points can be generated; active mobility and the transport modes of the Umweltverbund are given preference by the point system. With Florin, polluting molecules can be collected from the air while using or waiting for climate-neutral modes of transport, and then used to earn environmental points. The environmental points are conceived in such a way that users can spend them both in minigames as well as in challenges. In the challenges, users can compete by measuring their scores against those of others, create their own challenges, and invite others to participate. They also have the option of earning fictive objects (items), which can be used to customize Florin.

Generated over the course of the project were rough and fine concepts, as well as design documentations, which served as the basis for further program-side implementation of the minigames in the app. In a potential further development of the application, the interactive visualization of mobility behavior, the tracking, and the challenges can be implemented.

Summary

Technological challenges, along with those related to game concepts, were investigated based on two different research prototypes. The application FlowMo now allows researchers and users to acquire a full picture of the thematic concept, while at the same time, a technical proof of concept can be integrated into the application in a real environment. The user-centered development of the app can be regarded as positive for the process flow of thematic and technological research and should be continued in future projects. A survey on aspects of the app's technical functionality as well as an evaluation of the app's user-centricity in the sense of a usability test could not be carried out within the framework of the project (Hanington and Martin 2019: 242–243). Such surveys are recommended to evaluate the behavior-changing potential of the application.

The goal of creating incentives for environmentally friendly mobility behavior through playful rewards in a mobile application, which was already anchored in the preliminary concept, met with broad approval among the respondents of the user group. Respondents were also very interested in an individualized, visual representation of their mobility behavior and saw clear potential to change their behavior within occupational and infrastructural limits.



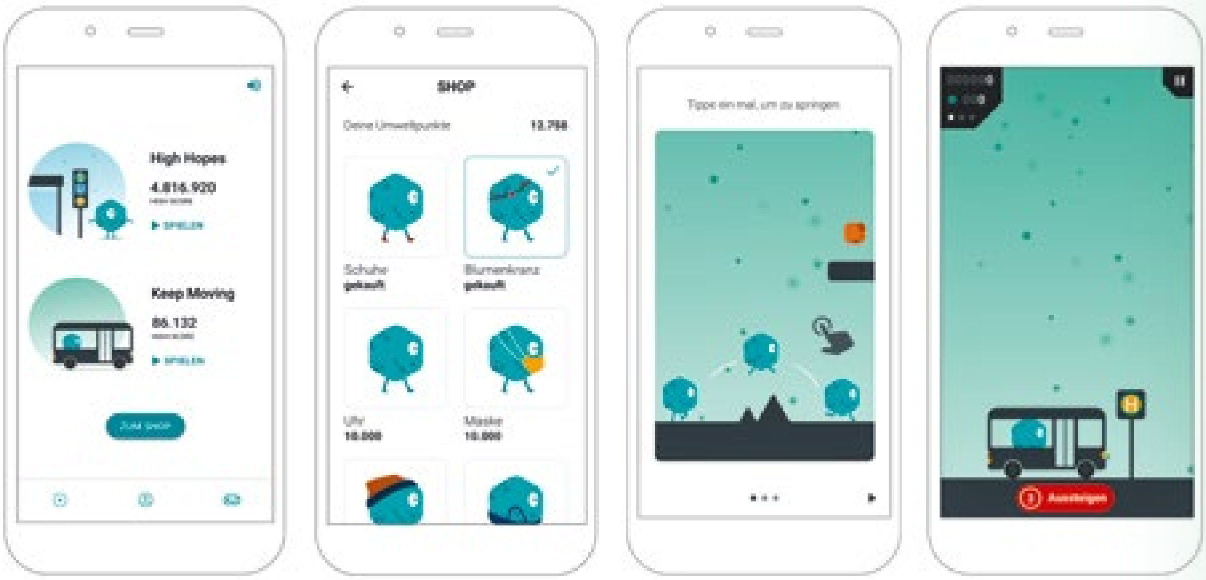


Fig. 2 Self-measurement component with tracking, challenges, and visualization of mobility behavior (Source: Silvio Lepszy, Sarah Lerch)

Fig. 3 Game components with the character Florin collecting pollutants; in the shop, items can be acquired for Florins. (Source: Silvio Lepszy, Sarah Lerch)

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Visionary Mobility

Designing the Data Environment

Mobility and the Future of Cities

Claire Gorman,
Fábio Duarte, Paolo Santi,
and Carlo Ratti

On December 24, 1900, the *Boston Globe* reported predictions for what life in the city of Boston might look like in the year 2000. The article's speculations speak to the concerns of city residents at the time and their fantasies for resolving them in the future: in 1900, downtown Boston suffered from the cacophonous gridlock of 400,000 people and 14,000 horses navigating a city center that occupied less than a square mile (McShane 2001: 277). It was said at the time that residents of Tremont Street could reach their destinations faster by walking along the roofs of stalled streetcars than by riding inside them (MBTA). Imagining idealized solutions to the crowding and congestion, the article predicted mobility innovations from a profusion of »auto-something-or-others« to moving sidewalks conveying pedestrians and airships flying over the city. However, it notes facetiously that »even airships would not solve the transit problem in a city like Boston« (Novak 2011).

Over the course of the twentieth century, cars and subways would take over from horses and streetcars; highways would widen the city's arteries; on-demand mobility would become accessible at the touch of a smartphone; the public transit network would expand to neighborhoods beyond downtown; and yet the problems of traffic, congestion, and inaccessibility would remain. While the overall comfort and speed of transportation have certainly improved in the last hundred (and twenty) years, the fundamental issues that frustrated Bostonians in 1900 still frustrate them today and are exacerbated by unequal access to mobility based on neighborhood and income. In a way, the *Globe*'s tongue-in-cheek pessimism turned out to be correct: none of the »airships« that emerged were able to solve the transit problem, in Boston or anywhere.

However, a new paradigm of data-driven mobility design is emerging that may smooth out the perennial transit issues that no single technology has been able to eradicate. Today's vehicles operate not only in a physical environment as they did in 1900, but also in a new and evolving *data environment* populated by information collected during every trip and controlled by the software of networked fleets, autonomous vehicles, and social media. The current and forthcoming waves of mobility innovations will operate on these forms of software, carrying out a transition from individualized, human-operated vehicles navigating unresponsive infrastructure to networked, intelligent mobility integrated with the built environment.

This chapter discusses four research projects conducted at MIT's Senseable City Lab that both describe and inform key turning points along this trajectory. By reviewing research focused on data analysis and networked autonomous mobility, it outlines the makings of a new era for transit, whose implications for transportation technology and city building are significant and intertwined.

Driving DNA: Individuals as Data Points

The road toward data-driven transportation begins with data analysis on the information already available from vehicles on the road today. Every car records thousands of signals from its controller area network (CAN) bus in order to ensure the correct functioning of the vehicle, expressing almost real-time information about the car itself, the behavior of its driver, and the surrounding environment. This stream of data—roughly a few gigabytes per hour—captures the actions of the car's driver as well as the tangible outcome of those actions that the driver can sense as a response, filling out the feedback loop that characterizes a given individual's driving style. The Driving DNA project[01] (Fugiglando et al. 2017) focuses on distilling the signals from the CAN bus that most meaningfully represent driving behavior, so that the tendencies of different drivers can be identified and compared.

The CAN bus of a car transmits data from 2,418 different signals, and this study evaluates 2,135 hours of that data, produced by an experimental group of 53 drivers who conducted 1,987 driving sessions in Ingolstadt, Germany, over 55 days.[02]

01 Partners: Allianz, Volkswagen Electronics Research Laboratory (ERL), Fraunhofer, Brose; Project Participants: Carlo Ratti, Paolo Santi (Project Lead), Emanuele Massaro, Sebastiano Milardo, Umberto Fugiglando, Fábio Duarte, Hyemi Song, Sarah Campbell, Louis Charron.

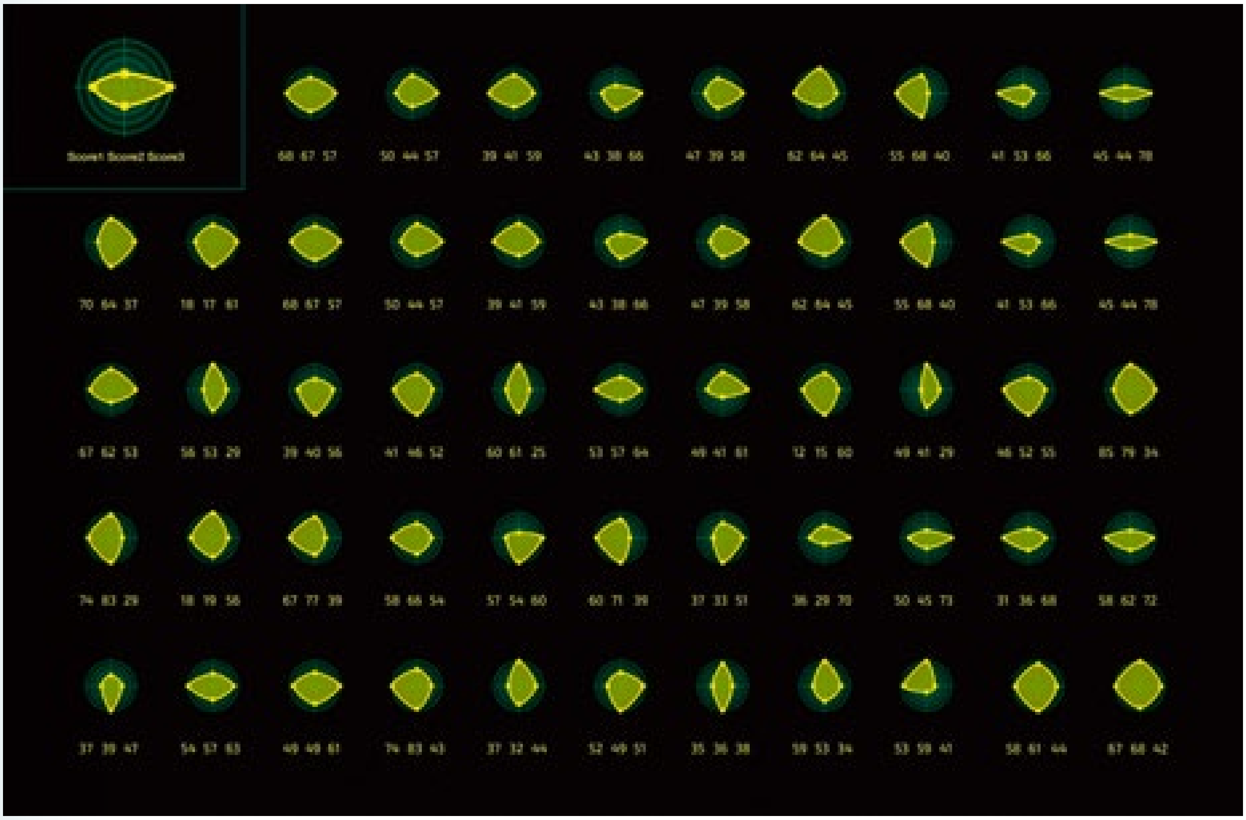

Fig. 1 Driving DNA »fingerprints« showing four-dimensional driver profiles as shapes corresponding to scores on four axes, with three different overall scores (arithmetic average, weighted average, maximized variance) below. (Fugiglando et al. 2017) Project URL: https://senseable.mit.edu/driving_dna/

Since the drivers were given no instructions or limitations regarding where or how to drive during their driving sessions, the experimental environment of this study should be considered uncontrolled, making it a close approximation of normal, unmonitored driving behavior.

To capture a driver's »DNA,« or behavioral profile, the study focuses on four particularly revelatory dimensions of the CAN bus data: frontal acceleration, lateral acceleration, speed in the context of the speed limit and presence of rain, and RPM (revolutions per minute of the engine's crankshaft) are interpreted as measures of cautious driving, attentive driving, safe driving, and energy efficiency, respectively. Each driver's behavior according to these characteristics can be visualized as a fingerprint: a shape stretched or compressed in four directions according to the driver's score for each metric. To encapsulate this information for purposes like driver ranking, three approaches were presented to represent each driver's behavior in a single synthetic score between 1 and 100: an arithmetic average, a weighted average, and a maximized variance based on principal component analysis (PCA). These three scores are shown beneath each driver's fingerprint in ↳Fig. 1.

Using the profiles and scores produced by the Driving DNA project, individual drivers can be characterized, compared, ranked, or sorted according to the unique behavior measured by their cars' existing hardware. This project offers a key step toward integrated and responsive mobility systems by efficiently representing the specific behavior of individuals who share the road in a way that is clear and comparable. Driving DNA establishes a notion of drivers and vehicles as data points existing together in a space that can be analyzed and

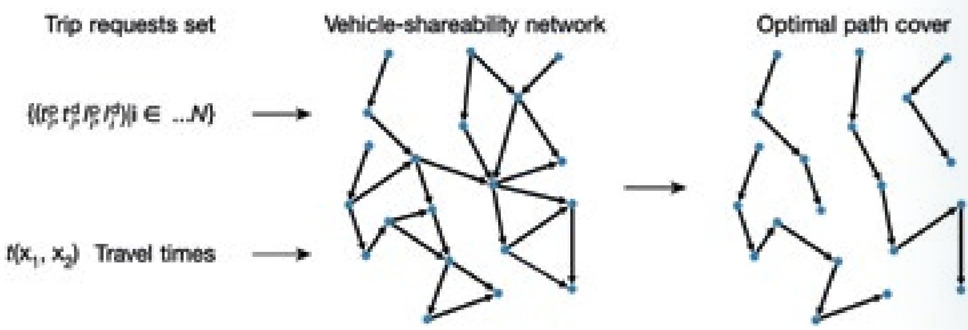

Fig. 2 Diagrams showing the vehicle-shareability network as an optimal path cover problem on directed graphs. (Vazifeh et al. 2018) Project URL: https://senseable.mit.edu/MinimumFleet/

manipulated, a concept that underlies the remaining projects described in this chapter.

Minimum Fleet: Optimizing Mobility Networks Based on Data

Expanding on the notion of individual vehicles as data points, the Minimum Fleet project[03] (Vazifeh et al. 2018) envisions a fleet of taxis as a set of mathematical connectors working together to meet trip demand. Currently, taxis in the city of New York spend hours a day circling the streets in search of a passenger to pick up, during which time they are empty and therefore not actively working to complete a trip. While each taxi driver individually tries to reduce this unproductive time, the typical taxi still spends only about 60 percent of its workday actually carrying a passenger. By moving beyond a model of vehicles as independent individuals and toward a taxi network that operates as a connected and optimized system, the Minimum Fleet project shows that it is possible to substantially increase the amount of time each taxi driver spends actively serving demand, and thereby significantly reduce the number of taxis necessary to complete every trip in the city.

The core of this project is a concept called the »vehicle-sharing network,« which translates the notion of a »shareability network« (Santi et al. 2014) to a minimum path cover problem on directed graphs, allowing the mathematical framework of shareability to govern a fleet of shared vehicles without requiring the actual sharing of rides. This approach furnishes a solution to the minimum fleet problem, which asks: given a set of trips specified by origin, destination, and start time, what is the minimum number of vehicles that can serve every trip without any delay to the passengers? By rendering this question in the field of graph algorithms, the Minimum Fleet project is able to solve the minimum fleet problem and also connect it to the fields of computer science and applied mathematics, such that computationally efficient algorithms for optimal vehicle dispatching can be achieved. ↳Fig. 2 illustrates this approach.

Though the optimal solution to this problem requires complete offline knowledge of daily mobility demand (possible only in a retrospective experimental context), a near-optimal online version of the algorithm, executable in real time for real taxi operation, can achieve similar results. With full knowledge of daily trip demand in advance, the vehicle-sharing network can reduce the necessary fleet size for New York City by 40 percent, with no ride-sharing or passenger delay. The online version of the algorithm follows closely behind it with a method that can be implemented in real time: it locally optimizes vehicle dispatching based on

02 The CAN bus data was collected through an experiment conducted by AUDI AG and Audi Electronics Venture in Ingolstadt, Germany, using a test fleet of ten Audi A3 vehicles.

03 Partners: Cornell University, Instituto di Informatica e Telematica (IIT), Consiglio Nazionale delle Ricerche (CNR); Project Participants: Carlo Ratti, Paolo Santi (Project Lead), Mohammad Vazifeh (Project Lead), Giovanni Resta, Fábio Duarte, Snoweria Zhang, Irene de la Torre-Arenas.

Fig. 3 Map depicting one minute of taxi rides with passengers in New York City, April 20, 2011, starting at 10 a.m. The left side, with the lines colored in blue, represents the Minimum Fleet optimization model; the right side, with the lines colored in yellow, represents the current taxi system. The dots signify destinations. (Vazifeh et al. 2018) Project URL: https://senseable.mit.edu/MinimumFleet/

brief samples of demand, allowing it to still serve more than 90 percent of trip requests with a 30 percent fleet reduction. ↳Fig. 3 shows a map of the taxi trips for one minute in New York City, with optimization based on the Minimum Fleet model (left) and without (right).

Importantly, this project's approach assumes that trip requests and vehicle-dispatching decisions are centralized, which is a model much more similar to app-based mobility operators than to the current management of taxi fleets. In this sense, the impressive reduction in taxi fleet size achievable with the vehicle-sharing network is also a reflection of the benefits of centralization for mobility dispatching. Of course, the reality of a monopolistic market or comprehensive state-controlled transportation operator is unattractive for reasons that may outweigh the attainment of a true minimum fleet. Luckily, the finding that the near-optimal online version of the algorithm delivers similar results to the optimal offline one indicates that most of the benefits of centralized vehicle dispatching are still possible in an oligopolistic market.

The Minimum Fleet project represents a triumph of the data-driven approach to mobility, framing a taxi fleet as a dataset that can be modeled and manipulated. This approach could be considered a transitional strategy to apply the principles of data-driven dispatching to a fleet of human-operated vehicles, such that a responsive and optimized system can be implemented while each taxi is driven independently. Also, this method can inform green policies in achieving carbon-dioxide-cap targets by reducing the fleet by 30 percent and still keeping the quality of service. Naturally, the absolute minimum fleet will be achieved only when limits on driver availability, maximum operating hours, and schedule coordination can be eliminated—by the adoption of autonomous vehicles.

Rebound: Predictive Personal Mobility

Autonomous driving revolutionizes the data environment in which vehicles operate, such that each vehicle is no longer just a data point in a larger system of monitoring and management, but instead an agent with its own operating system whose contribution to the larger fleet or network is self-directed. In another scenario of fleet minimization, the Rebound project[04] (Kondor et al. 2021) investigates the benefits of self-repositioning capabilities for dockless, shared personal mobility devices, such as bike-share systems or electric scooters.

Unlike taxis, which actively circulate around the city in search of new passengers, contemporary implementations of shared personal mobility devices serve their trips and then remain stationary at their users' destinations. This results in a distribution problem, in which extremely popular drop-off locations become oversaturated with shared mobility devices, while devices ridden to uncommon destinations are left stranded and ill-situated to serve demand. The Rebound project proposes a solution to this problem in the form of »self-repositioning shared personal mobility devices« (SR-SPMDs), which are small electric scooters that must be driven by their user during trips but can move autonomously to reposition themselves at optimal pickup locations during downtime.

The project evaluates this concept according to the vehicle-shareability network established by the Minimum Fleet research, using data from short shared bicycle and public bus trips in Singapore. It finds that self-repositioning functionality represents a significant improvement in terms of fleet minimization and vehicle utilization, but that relocation speed is a key determinant of the viability of an SR-SPMD model, regardless of its demand knowledge. In order to enable SR-SPMDs to autonomously self-reposition fast enough to improve the fleet's overall performance (15 km/h), significant infrastructure improvement would have to be completed to smooth and separate the paths taken by self-repositioning devices. Further study of the Rebound model found that this could be achieved if separate paths specifically for personal mobility

04 Partners: Singapore-MIT Alliance for Research and Technology (SMART); Project Participants: Carlo Ratti, Dániel Kondor (Project Lead), Xiaohu Zhang, Paolo Santi, Fábio Duarte, Dylan Halpern, Guangyu Du.

Fig. 4 RoundAround autonomous bridge rendering, showing two ramp docks and Roboats shuttling in a circular path between them. (Leoni et al. 2019) Project URL: https://senseable.mit.edu/roundaround/

devices and SR-SPMDs were constructed parallel to existing bicycle and PMD routes.

This research explores the benefits of an intermediate form of limited autonomy, in which SR-SPMDs optimize their availability to serve mobility demand without subjecting passengers to the slow and defensive driving style associated with fully autonomous navigation of a pedestrian environment. In this project, as in the previous examples, an existing technology (here, the scooter; elsewhere, cars and taxis) is reimagined according to a new operational or management protocol that reframes its role in the broader transit system. Rebound advances this trajectory by suggesting a tandem evolution of mobility and infrastructure.

RoundAround: Autonomous Vehicles as Infrastructure

As autonomous vehicles (AVs) improve, they will influence the design of the built environment, creating a conversation by which mobility solutions and infrastructure can coevolve. Today's AVs are designed to navigate a physical environment of streets and traffic largely unchanged since 1900. But as their adoption increases and the data environment of future mobility becomes primary, the city will have to respond: fewer cars on the road, liberated parking spaces, and faster travel with the elimination of traffic induced by human error will free up entire categories of public space traditionally reserved for vehicles. As these infrastructures become obsolete, new approaches to city building will become necessary.

The RoundAround project[05] (Leoni et al. 2019) blurs the line between vehicle and infrastructure, envisioning a future of autonomous mobility solutions that operate not only as independent agents of transit but also as infrastructure in motion, coordinated to accomplish flexibly and intelligently what today's infrastructure does with unresponsive permanence. This research is part of the broader Roboat research initiative at the Senseable City Lab: a five-year partnership with the city of Amsterdam to design and test autonomous electric boats for the city's canals as a creative solution to the problems of traffic and litter. The RoundAround project presents one of many use cases for the Roboat vehicles: the design recasts a set of ten

Roboats as a bridge, choreographing them to travel in a circular pattern between two docks in order to shuttle passengers from one side of a canal to the other, as shown in ↳Fig. 4.

Connecting the neighborhood of Marineterrein directly to the city center of Amsterdam, the RoundAround bridge eliminates what is currently a ten-minute walk between the two areas. The design includes continuous ramps on each side of the canal that convey pedestrians from street level to water level, terminating in open-sided platforms with contact points for Roboats to momentarily dock as passengers board. The Roboats travel in a continuous circle that links the two sides of the canal and could be dispersed or reassembled with a simple change in programming, though they are always able to respond intelligently to obstacles or other vessels using cameras and laser scanning technology (LiDAR). RoundAround is a compelling use case for the Roboat vehicles, of which the first full-scale prototypes set sail in spring 2021.

The RoundAround design envisions a crossover between intelligent vehicles and responsive infrastructure, offering a glimpse into a future of cities shaped by networked smart mobility. Framed as the furthest point on the trajectory that connects the data environment of individual vehicles and optimized connected fleets to that of autonomous vehicles and responsive environments, this project extends data-driven mobility into the sphere of urban infrastructure.

Conclusion

This chapter has discussed four research projects conducted by MIT's Senseable City Lab, all of which offer imaginative contributions to the future of connected, intelligent mobility. *Driving DNA* establishes a basic technique of vehicle-based data analysis, mobilizing the information already transmitted by today's cars to create a quantitative representation of driver behavior. *Minimum Fleet* expands this notion of vehicles as agents in a data environment by solving for the optimal taxi fleet size for New York City, according to the innovations of demand sensing, centralized dispatch, and the novel vehicle-sharing network. The *Rebound* project applies this mathematical approach and integrates limited autonomous driving, considering how fleet dynamics change when each device in a shared personal mobility system is able to anticipate demand. Finally, *RoundAround* imagines the broader implications of AVs, interrogating their impact on the city by blurring the boundary between vehicle and infrastructure through autonomous boats choreographed to form a bridge.

As the mobility innovations of the twenty-first century unfold, these studies support a prediction similar to that published in the *Boston Globe* in 1900, that »even airships would not solve the transit problem.« None of these projects are airships: while they operate on different types of vehicles, some of which are particularly innovative (Roboats, for example), their central contributions are not in the sphere of physically engineering new modes of transit. Instead, they operate on the data environment in which today's vehicles exist, gathering information from those vehicles and using it to drive new approaches to the management, deployment, and choreography of mobility solutions.

This data-driven mobility paradigm transcends the vehicles themselves and points toward a robust and flexible urban operating system, in which transit and infrastructure develop and improve together. It manifests as an »intelligence« that is equally transcendent of scale: these projects lay track for a future of mobility that is not only endowed with predictive functionality at the level of the vehicle, but guided at the network level by an adaptive mode of development and governance shaped by consistent data collection, analysis, and response. In their examination of present mobility data, the projects discussed here expose the status quo and respond to it with innovations maximizing safety and efficiency. The future of this data environment will be shaped bilaterally by the sensing devices that generate its constituent information and the analytical procedures established to parse and operationalize it. According to

05 Partners: Amsterdam Institute for Advanced Metropolitan Solutions (AMS); Project Participants: Carlo Ratti, Fábio Duarte (Project Lead), Pietro Leoni, Lenna Johnsen.

this structure, the achievement of goals like equity of access and green urban systems will depend not only on the engineering of fair and sustainable mobility infrastructure but on the information produced by that infrastructure and the questions we ask of it. Thus, if the Senseable City Lab were to register a prediction for transit in the remainder of the twenty-first century, it would rest on the idea that any mobility solution is most powerful when it is connected, responsive, and driven by data.

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Perspectives on the Design of Expanded Mobility

Andrea Krajewski and Sabine Reitmaier

In the last decade, digital technologies have increasingly found their way into mobility systems. As a result, the character of mobility has been altered so fundamentally that we can now speak of *expanded mobility*. However, this expansion of the potentialities of mobility behavior is far from concluded; instead, the progressing digital transformation of the mobility sector can be expected to offer new perspectives and challenges for mobility design. This essay sketches out some of the emerging design dimensions of expanded mobility and offers instances of the way in which some of the changes and user expectations brought about by digitalization will have an impact on the potential design of mobility systems.

The first part is devoted to the issue of the influence of digital technologies on mobility, and based on this, offers a definition of expanded mobility. The second part addresses some of the central user expectations in connection with already existing digital or digitally supported products that have resulted from the use of digital technologies. Extrapolated from this discussion will be some prospects for the design of expanded mobility.

In this context, the central terms are future design, digital design, digital transformation, Internet of Things (IoT), IT and mobility, mental models, mobility design, mobility research, Mobility as a Service (MaaS), smart city, smart home, transformation design, transport policy, user experience, future mobility, and future research. Indispensable for a closer look at these issues is disciplinary knowledge from the areas of interaction design and design methodology. We have selected scientific contributions and fundamental works from the field of design methodology (in particular digital design).

Dimensions and Definition of Expanded Mobility

We understand the term *digital technologies* to mean the interplay between hardware, software, and networks. These technologies influence business models, courses of action, and social interaction. Their application impacts not just the framework conditions of planning, design, and utilization, but also our understanding and definition of mobility. We are headed toward a living environment whose buildings, fixtures and furnishings, devices, transport resources (in short: whose »things«) are increasingly networked with one another in the Internet of Things (IoT). »It is estimated that more than 30 million IoT devices were installed in the course of the year 2020 worldwide, and that this number will more than double by the year 2025« (BMBF 2021). Supported by machine learning, these things are able to act autonomously or in systems to offer situational services and to make decisions on behalf of human beings and the environment. Interfaces of diverse kinds, such as smart phones, terminals, watches, smart clothing, or even the environment itself, provide users with controlling access to the total mobility system and its various services. This results in a variety of expanding dimensions for the concept of mobility.

The *market* dimension: the pool of providers on the mobility market is expanding, and reshaping mobility as such. From international IT concerns to housing associations, and all the way to regional networks, new protagonists are emerging and offering mobility services from their diverse perspectives. Even more, through the IT-supported components of the means of transportation, such as passenger automobiles (peer-to-peer sharing), participants in transport activity who were previously merely consumers are now spontaneously becoming mobility providers (Lanzendorf et al. 2017: 142). In the future, mobility will not simply be made available to as many people as possible by a central authority in a maximally neutral way, but instead will consist of a spectrum of offerings that are freely available to individuals depending upon their requirements. This also means that the boundaries between individual and public passenger transport are becoming blurred.

The dimension of *supply*: the reconceptualization of the concept of mobility as a flexible mobility service (Mobility as a Service, MaaS) with the assistance of coordinating software will only function in an economically and ecologically appropriate way if public transport and shared mobility are merged (for example, through the integration of digital interfaces, physical infrastructures, as well as ticketing and timetables; see ITF 2021: 35). This has not yet occurred to an adequate degree. Canzler and Knie compare our currently confusing world of mobility »with the condition of the Internet before the invention of browsers« and propose, as a real-world experiment, a »browser« for the transportation system. They referred here to a »change through a digital demonstration of the possible« (Canzler and Knie 2021: 298). In the future, mobility will be conceived as a multi-optional service which users will have access to at any given place, at any moment, individually, and centrally bundled.

The *environmental* dimension: in order to give form to an environmentally compatible mobility system, it seems advisable to consider concepts of greater complexity: namely, taking larger interrelationships into account by coordinating them and conceiving of them as units that can be integrated into the total mobility system as we develop a strategy for the »transformation of transport.« If cleaner energy is required for mobility, for example, then the process of its production and distribution could also become a consistent aspect of the mobility concept. An example of this is the participation of the citizenry in the production of clean energy for vehicles through their own homes (Honda 2021; Fast Company 2014). Batteries for public transport infrastructure also have the potential to serve as intermediate energy storage facilities in a connected energy grid concept. Vehicles parked at specific locations could either become charged or feed power back into the grid via a system of wireless energy exchange (Witricity 2018). In the future, environmentally friendly mobility will not merely solve the problem of transport between point A and point B; it will also use digital technologies to achieve this as cleanly as possible within the framework of a larger infrastructural solution.

Based on the dimensions discussed above, we define expanded mobility as a digitally supported system consisting of hardware and software that is interlinked in networks. By hardware, we mean all of the material objects of the mobility system (means of transport, infrastructure, and interactive devices such as smart phones, computers, wearables, etc.); by software, we mean their digital expansions. Mobility options will be made available by various protagonists (including participants in transfer activities themselves) as a system as multioptional services.

What Kind of Perspectives for the Design of Expanded Mobility Emerge from User Experiences with Digital Products?

The utilization of products or systems presupposes that users possess an experience-based, partial, conceptual notion of how they are to be handled, and what consequences or meanings result from their use. This is also known as the concept of the »mental model« (Dutke 1994; Krippendorff 2013). Interaction designers in particular address the preexisting models of users, with the aim of giving such interfaces and interactions a »natural« feel. In searching for the appropriate model, software ergonomics speaks of »expectation conformity« as one of seven criteria for the dialogue design of interactive systems (DIN EN ISO 9241-110). In coping successfully with a new situation and its associated artifacts and systems, users are also quite capable of applying concepts familiar from other empirical areas (Krippendorff 2013). To do so, they simply require points of reference that are supplied to the design or behavior of the relevant artifact. This fundamental cognitive flexibility in humans can be strategically exploited in mobility design in order to give rise to new mental models that foster the transition to the expanded mobility system. This is vital if users are to acquire the kind of cognitive access that renders the potential of innovations comprehensible and practicable. Regarding design, adherence to now defunct models can retard the success of progressive mobility strategies and lead to user frustration due to the anticipated divergence between model and reality. During the early history of the automobile, for example, the mental model of the »horseless carriage« prevailed for a considerable period of time. Motorized vehicles, therefore, were steered using reins, which entailed various problems (safety, turning radius) that were in turn eliminated through the adoption of the mental model of the steering wheel of a ship. Here, access to new perspectives becomes a strategic aim of mobility design.

Mental models emerge through the stabilization and perpetuation of lived experience. They cannot simply be »invented« by a third party and applied in a particular instance unless the corresponding experiences have been internalized by the user and stored as a model (Dutke 1994). Since digital technologies form the basis for expanded mobility and will strongly influence mobility behavior in the future, the question arises from a design perspective: how can the preexisting mental models that developed through the application of digital technologies in other areas of life be transferred successfully to the design of expanded mobility? This will be exemplified with reference to four mental models.

Model 1: Customized Options Are Immediately Available Digital networking, in conjunction with data collection and analysis, makes possible options for personalized information, communication, and services that are available at any times. Moreover, »the qualities of durability, stability, and reliability are given less precedence than being optional, flexible, and revisable« (Canzler et al. 2011: 293). This means a growing demand on the part of consumers and citizens for the immediate accessibility of personalized products and services in parallel optional offerings (multi-optionality). Through human-centered design, moreover, the users of interactive systems have become accustomed to enjoying a central status. It is a question here of a design process aimed at developing and configuring interactive products, namely by analyzing the needs of users and implementing their participation through an iterative process (also referred to as participative design) (ISO 9241-210:2019). This differs radically from the public transport services offered by cities and municipalities, which cover only fixed routes using uniform vehicles and carry as many people as possible while following strictly fixed schedules.

Perspectives for mobility design: users are accustomed to being the focus. A selection of both functionally and emotionally customized services and experiential options are accessible to them situationally and without delay. This means a rethinking of the provision and design of accessibility to mobility options. These cannot be available only at certain places where travelers are obliged to present themselves; instead, transport services must come to them—and in all conceivable ways. This pertains not only to the availability of and access to mobility services via software, but also forms the basis for fundamental systemic offerings and for the design of mobility as the interplay between services and product experience.

Model 2: Data is Used for the Common Good

Data is required by service providers in order to learn about user behavior, allowing them to optimize products and services economically and orient them so that they become situatively relevant. Available today are a multiplicity of combinable methods. In the area of mobility, data is generated at many stations within the value creation chain with the help of various devices (smartphone, smartwatch, ticket vending machine) and vehicles (from loan scooters to intercity express trains), and can be combined into a single profile. The question of who uses data, and for what purpose, has been taken up by the growing open data culture, and a model concept developed (bpb 2011). The objective is to evaluate data in an open, transparent way for the sake of the common good. To this end, data is »donated« by data-generating users.

One example is the Open Data Portal for the city of Berlin (Berlin Open Data 2021). The aim is to make data available for evaluation by humans or machines. Both citizens as well as the providers of mobility services can benefit from the available data. A broader context for the mobility sector is allowed for by the project Mobility Data Space, sponsored by the German Ministry for Digital and Transport (BVMI). This can be described as a »data marketplace where equal partners from the mobility sector exchange data in a self-determined way for the sake of facilitating and further developing innovative, environmentally and user-friendly mobility concepts.« Moreover, it allows users to »participate in the value creation-potential of their data« (acatech 2021).

Perspectives for mobility design: data is not a technical waste product of mobility over which data collectors can freely dispose; instead, it belongs to the extended identity of the user. Mobility design should therefore ensure that data and its secure handling are perceptible and achievable. On the other hand, data is necessary if products and services are to be offered in an environmentally friendly and customized way. The collection, transfer, analysis, and storage of data requires well-defined, mandatory guidelines and processes. Users of mobility services should have the freedom to share or withhold their data, and compliance by data users should be verifiable simply and without the need for special requests. These regulations should be valid for an entire region and should not be dependent upon individual service providers. Mobility design regards data as a component of user identity that is worthy of protection, and must consciously shape the process of negotiation that allows for the use of data.

Model 3: Consumers Become Producers Beginning in the year 2005, the makers of the early Internet of Things set a formative do-it-yourself movement into motion, one that soon went beyond electronics and was no longer confined to a small community. Ever since, normal people have hacked nature and the environment and conducted research in the framework of civic science projects to repurpose everyday objects and create their own digital-analog world. In Germany, for example, the magazine *Make* offers tips on the allocation and utilization of everyday technical equipment. One segment shows how to connect the subsidized wall box of your domestic photovoltaic system for the free use of solar power, to be achieved with ease over two weekends (Rohne 2021). The new »prosumer,« a hybrid of consumer and producer, strives to shape the development and design of the environment, and is no longer satisfied with market offerings. The expectation of an environment that is adaptable single-handedly at any moment to personal needs is transferred now to the analog environment. Experts in cultural studies refer to this phenomenon as »post-digitality« (Stadler 2017: 18). The cultural theorist Florian Cramer maintains that »new ethical and cultural conventions, which became mainstream with internet communities and open-source culture, are being applied retroactively to the production of non-digital and post-digital products« (Cramer 2014: 18). The digital transformation is not just relevant to digital products, such as mobility apps, autonomous vehicles, and navigational systems. It also characterizes the culture and way of thinking of citizens and is therefore something planners and designers must take into account. In short, converging in the design of mobility systems are logistics, planning, and experience, which are now placed in the hands of the co-designing passenger. This participation can be positioned either upstream or downstream. An essential criticism of cities with digitally supported processes is that the dominance of entrepreneurial competence and interest in the area of digitalization means that citizens are for the most part regarded mainly as consumers. They mutate now into subjects who can be guided and controlled (Cardullo et al. 2019). Rather than encouraging citizens to become active, engaged participants, civic involvement is reduced now to the testing of predetermined solutions (Sochor et al. 2017). Criticized in the research on the topic of the Smart City was the discrepancy between the promise and the actual implementation of participative processes (Follmann et al. 2021).

Perspectives for mobility design: beginning with the emancipation of users in developmental and repurposing processes, mobility solutions should be designed in such a way that they can be adapted, or hacked, by users as needed. This means a break with the classical strategy of providing predetermined solutions. Instead, building on a universal design approach, additional target group options should be designed and made available. At the same time, the new generation of hackers should be integrated as representative of interest groups into the joint planning and design processes of mobility design. An example of this is the Verschwörhaus in Ulm, which launched an independent initiative for the construction of OpenBike-Sensors, which allow cyclists to find out on which streets and at which times of day conditions are particularly crowded for riders (Kaufmann 2021). Given increasing demand for legitimation on the part of civil society with regard to large-scale transportation planning projects, it is »advisable to reflect upon tools for participation and design that offer those affected with opportunities to articulate their needs, and in some cases to become co-designers« (Kollosche 2016: 931). Meanwhile, participatory models are being promoted politically, as illustrated by the numerous programs supported by the various German ministries (Ibert et al. 2018).

Model 4: The Environment Reacts to Users The possibilities inherent in the increasing fusion of digital and physical products, their supplementation through sensor technology, and their networked data exchange through the Internet of Things (IoT) has prompted designers in this field to design not individual products, but instead interrelated, adaptive artifacts in networked ecosystems that have the capacity to respond to users independently. Through its digital and sensor equipment and networking options, the Nest Thermostat could quickly become the hub of a complex services ecosystem that revolves around »comfortable living« (finanzen.net 2014). Lighting, temperature, air quality, and the operations of household appliances such as washing machines and robot vacuums are able to function autonomously through data exchanges concerning weather, whereabouts, and user preferences, depending upon the context and in mutual dependence. If a user should arrive home late, the smart home »realizes« this (via networking with a smartphone or automobile) and reacts accordingly without the need for active intervention. From the user perspective, the individual product within the network and its isolated operation retreats into the background in favor of services that are coordinated with his or her behavior. With design concerned now with shaping the available options of a participant within a network, this task area tends to blur the boundaries between the design of services, interactions, products, and architecture (Rowland et al. 2015: 4–27).

Perspectives for mobility design: since users now expect the environment to adapt itself to them autonomously, the focus of design today is no longer exclusively on the human individual, and instead to an increasing degree on his or her interplay with a dynamically changing network (Redström and Wiltse 2019) that consists of diverse protagonists that must be orchestrated with the aim of socially acceptable and sustainable transport. Through an expanded concept of design, this would allow mobility design teams to tackle complex challenges. For example, the Dutch design studio Incredible Machine, together with the research and innovation center elaadNL and the network manager alliander, developed and designed a transparent, intelligent charging algorithm, with corresponding charging stations, for the city of Eindhoven (*The Incredible Machine*, 2017). The aim here was to provide the equitable and transparent charging of electric vehicles, even during peak demand for energy supplies, by algorithmically establishing charging speeds and quantities and adjusting these to the user's demand profile.

Summary and Prospects

Expanded mobility refers to the perspectives that are opened up by the use of digital technologies. However, the transformation of mobility that is associated with this term is fundamental. It affects services, providers, users, and intermodal mobility processes in a networked mobility space. Those active in the field of mobility design must consider the significance of this change for the design of future mobility systems and conceptualize a commensurate extension of the concept of design itself. Increasingly, the merging of network hardware and software tends to blur the boundaries between products and services.

The mental models that arise through the use of digital media shape the expectations of a future expanded mobility and define points of orientation for design objectives: accessible, multioptional, continuously available services that are simply and independently adaptable to the functional and emotional needs of users, and that are seamlessly interlocked in a readily comprehensible way in a smart, environmentally friendly environment consisting of hardware and software. As we have demonstrated, design can adopt existing mental models and link these to a conception of expanded mobility, thereby contributing to the formation of a new mental map of mobility. The common basis for the development and design of mobility services consists of the personal, process, and usage data belonging to the users. As a result, providers and users become negotiation partners and co-designers. This also means an extension of the position of the designer, who now mediates between desirable possibilities.

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Transportation in Transition

Theses on the Future of Urban Mobility and the Role of Mobility Design

Stephan Rammler

We live in a transformative time, a fact that has achieved wide recognition. The phrase *great transformation* was originally coined by Karl Polanyi (1973), referring to the profound change that led to the evolution of capitalist market societies and nation states. Today, in discussions of sustainability, the term *great transformation* refers to the directed, systemic, and collaborative socio-ecological reshaping of our society at a time when the synergy of megatrends such as population growth, urbanization, climate change, digitalization, and multiple geopolitical upheavals, all taking place within inherently limited planetary boundaries, have up to now taken the shape of a chaotic transformation *by disaster* (Rammler 2016; Beer and Rammler 2021).

With a focus on mobility, and with the above-described background in mind, this essay asks: what kinds of challenges are likely to confront the design field in relation to such a socioecological transformation of mobility *by design* (Rammler 2015, Bormann et al. 2018)?

One focus is on the influence of urbanization and the associated densification and scarcity of space on the mobility of the future and the resultant challenges for the design of transportation systems, especially given the urgent necessity for climate-neutrality and post-fossil-fuel approaches.

Given this situation, an additional focus is on the likely future tasks and working approaches of mobility design, which can for the moment be regarded, firstly, as an intermediary interface discipline between the most diverse urban, spatial, and transport-related disciplines; and, secondly, between design and planning practices and the user experience.

Thesis 1: Cities Are the Modernization Laboratories of Solar Culture: The Urban Mobility of the Future Must Be Space-Saving, Postfossil, and Climate Neutral

Given the multiple negative externalities associated with the burning of fossil fuels, the fossil-run battery of spaceship Earth—to cite the neat formulation of Buckminster Fuller (1973)—has reached the end of its lifetime. In the coming years, the resultant vulnerabilities, distribution conflicts, and demands for resilience and adaptation can be expected to dramatically escalate (Rammler et al. 2022). The only alternative to the present situation is to quickly start up the main engine of the spaceship, which is to say to affect a conversion of our primary energy source to a regenerative, and ultimately a solar, one. This has massive implications for the tasks facing the redesign of our transportation system, currently bound up with fossil fuels.

Another key factor for future mobility is urbanization, or the densification of a steadily growing world population in a restricted geographical space. Today, a large proportion of the world's population already lives in urban regions. This proportion is expected to grow. This means that the future of mobility will be determined primarily in the city of the future. Alongside energy provision, habitation, and the resource or circular economy, urban mobility is one of the core themes that require new approaches to problem-solving if we are to advance toward a viable total concept for sustainable urban development (Schwedes and Rammler 2012; Rammler 2017: 59f. WGBU 2016). The increasing scarcity of space and the resultant distribution conflicts concerning urban life opportunities also means that the prospects of mobility for an increasing number of people, together with growing demands for prosperity, can only be satisfied by increasing efficiency in the utilization of infrastructures and vehicles.

The *conversion of energy culture*, and our approach to dealing with increasing *space scarcity* are the two most important transitory elements of urban development in the twenty-first century. On this basis, we can distinguish at least three design guidelines (Schwedes and Rammler 2012) that are vital for a sustainable future mobility:

- *SunCity* is an urban model for the post-fossil-fuel recultivation of the planet and the decarbonization of the energy flows of the urban organism, in particular its traffic and transport flows.
- *ElectriCity* marks a paradigm shift toward the electrification of all urban subsystems, in particular, that of mobility. In the future, it is regeneratively produced electricity that will

make it possible for us to renounce fossil fuel energy sources and their combustion emissions.

– *NetCity* refers to an information-based, decentralized network culture of complementary energy and data flows, and the resultant new possibilities for the management of collaborative and usage-efficient product, or the sharing economy. Manifest is the particular importance of digitalization for the facilitation or optimization of new interfaces for overall systemic innovation between hitherto separately operated urban functional systems, such as mobility and the energy system.

Up to this point, modern, Western-style cities have been thoroughly fossil-fuel-based; their origins, formation, and development have been conditioned by the use of fossil fuel energy sources. Logically, and given the political priority of attaining climate neutrality in the transport sector as quickly as possible, Western societies—which remain strongly wedded to the automobile—should begin where the principal problem emerged under the conditions of spatially dispersed, strongly suburbanized settlement and commercial structures: with the oil dependency of a gigantic fleet of vehicles, and with a rapid attempt to reduce consumption and transform drive forms.

At the same time, and in the urban context in particular, public transport, with its capacity for bundling, will remain »the backbone of the transformation of transport« (Rammler 2011), if only because escalating space problems render impracticable the wasteful space economy of stationary and moving private and individual car traffic that has prevailed up to this point (Rammler 2017: 59f.). Then there is the new mobility—concepts such as ridesharing, the renaissance of cycling, micromobility, the logistics of delivery—and new concepts for local mobility, components which together form a set of instruments for a *functionally integrated urban transformation of transportation*.

Against this background, three strategies can now be distinguished which, when interlinked, point toward the future by providing innovative concepts for the design of mobility systems, mobility utilization, and mobility products.

Thesis 2: Efficiency Strategies Quickly Reduce Resource Use

Here, it is mainly a question of increasing resource productivity through the accelerated reduction of the use of vehicles based on the internal combustion engine, and the optimization of the cycles of the materials employed, which can be referred to as »efficiency strategies« in connection with the usual discussions of environmental policy. But the enhancement of efficiency is and remains a transitional strategy, which must diminish in importance over time. Potential for savings can be found in the area of weight reduction, the minimization of aerodynamic driving resistance and tires, and in the optimization of engine performance.

The technological potential that lies dormant in these areas continues to be enormous. In the past, under unvarying regulatory conditions, improvements in the efficiency of automotive engineering have been lost to the rebound effects or been canceled out by changes in behavior brought about by the reduced user costs of more efficient vehicles (i.e., drivers use cars more frequently or accept greater distances) (Rammler and Sauter 2016). Indispensable against this background is that technical regulation on the production side be complemented by fiscal policy recommendations that have an impact on behavior, such as carbon-dioxide taxation or a toll system.

Thesis 3: The Conversion Strategy Requires a Revolution in the Construction, Design, and Propulsion System of Individual Vehicles

Efficiency strategies must be supplemented by a change in propulsion systems based on a technological paradigm shift in automobile construction worldwide. The guiding principle of this conversion strategy must be a vehicle design that is completely restructured technologically in relation to the internal combustion engine. The automobile of the future will be extremely lightweight, safe, and powered by electricity. Modular and flexible construction concepts and innovative interfaces and concepts in the interior based on new digital technologies will mean transport options with higher functionality, individualization, and networking within the larger transport system. The automobile of the future will be characterized by superior design values and aesthetic appeal, and its components will be reusable in the framework of an automobile economy that is, in turn, integrated into a total circular economy. Arguing in favor of this, unequivocally, are the large resource backpacks that are required by the new propulsion concepts.

It remains an open question how the electronic motor will be powered. It could be a fuel cell or the still prevalent battery electricity, with the battery being charged by a power grid that is technologically modernized and restructured for flexible sector coupling. In the coming years, a competition may emerge between the electric battery and hydrogen (H2) fuel cells. It seems extremely likely that both sectors will soon see considerable advances. Appropriate in the current situation, however, would be cooperation between the two contexts of use rather than a competition between the two technologies, which could lead to a premature closing off of options.

Nevertheless, there is no »savior vehicle« in the offing. No new vehicle technology—not even the electric automobile—will be able to replace fossil-fueled automobility in its current form through a single, fully functional equivalent without violating sustainability requirements in essential ways or giving rise to new resource bottlenecks. Individual mass motorization can never become a global mobility model, regardless of the technological basis involved (Rammler and Weider 2011; Rammler et al. 2021; Brunnengräber 2020). All the same, it is vital that the technology of electrical automobility be developed in all of its variants at an accelerated tempo.

Thesis 4: The Integration Strategy Has the Task of Ensuring that the Transport and Energy Systems Are Embedded in the Conversion Strategy

Cities are networks of infrastructures. With regard to transport and energy systems, the aim of the integration strategy is a radically altered linking and integration of (individual) vehicles into the total organism of urban energy and material flows. This system-innovative technological and infrastructural approach should therefore be referred to as an integration strategy. Conversion and integration strategies belong together; they are two sides of the same coin. They are the decisive and the most effective point of departure for the post-fossil-fuel restructuring of transport, but at the same time the most difficult.

Above all, the electrification of urban mobility requires a comprehensive reconceptualization of *energy-systemic integration* and must clarify the following questions: How and where will the required energy be provided in a regenerative way? What role will be played by wind power, solar thermal energy, hydropower, and biomass power generation in various regions? How will regenerative energy be stored, thereby compensating for natural production fluctuations? What role could be played by sector coupling between energy provision and decentralized automobility? Will new supply infrastructures be required, or can the conventional power network, albeit modernized, be used as a distribution infrastructure?

Clearly, the realization of the conversion strategy for both technology lines—hydrogen fuel cells and battery electricity—have far-reaching implications for the reorganization of energy provision overall. It is also clear that in the future, mobility, energy provision, and household energy use will need to be conceived as a total system. This could allow new players to become active in the arena of automotive policy. From this perspective, the petroleum and electricity industries clearly become competitors. Conceivably, precisely the parallel development of the technology lines of hydrogen fuel cells and battery electricity could lead to a cooperative perspective. In this model, the electricity sector would be responsible for passenger transport based predominantly on battery electricity. The petroleum industry would assume responsibility for the hydrogen infrastructure.

The *integration of the transportation system* must clarify the following questions: Which intermodal service and utilization innovations would be in a position to address the range problem, which cannot be fully eliminated, in relation to new vehicle concepts based on electrical drive systems (rail-street cooperation)? What role could be played by new driving assistance and traffic guidance technologies for the optimization and bundling of the traffic flows of both private and collective modes of transport? How can interaction—meaning intramodal cooperation—between the subsystems of public transport be improved, and how might collective-public and individual-private mobility concepts such as the automobile and the bicycle cooperate better in the future? What role is played by the first and last miles, and which transport services, beyond the private automobile, provide users with adequate functionalities from a user perspective?

In the mid- and long-term, the integration of the transport system will be of enormous significance for the sustainable and post-fossil-fuel reinvention of urban mobility. In the metropolitan regions of southern Asia, in particular, as well as in Germany, sustainable economic and social development will be impossible without the reliable backbone of a highly efficient and high-performance mass public transit. Given the massive competition for space, the establishment of a Western-style monoculture based purely on the automobile—even on a zero emissions basis—in densely populated Asian metropolitan regions would be counterproductive; in contrast, the accommodation of individual and collective transport seems highly promising. In regions that are still playing catch-up vis à vis modernization, density problems are decisive. This becomes striking when we compare the density levels of the Chinese province of Guangdong with those of the German Federal State of North Rhine-Westphalia. In the foreseeable future, approximately 100,000,000 people—roughly the same population as Germany and the Netherlands combined—will be living in the mega-urban region of the Chinese Pearl River Delta, which is roughly the same size as North Rhine-Westphalia (Schwedes and Rammler 2012).

Thesis 5: The Future of Urban Mobility Lies in the Development of Integrated Mobility Systems

Integrated, versatile, and regionally adapted mobility concepts are the urban mobility solution of the future. An *investment and modernization offensive* for collective transport modes (local public transport, long-distance and regional trains, rail freight transport) is the linchpin of a politics of sustainable mobility. Given the central importance of mobility for modern societies, such an investment is defensible in all regards. The linking of so-called micromobility (bicycles, e-bikes, light electric vehicles, light electric transporters, Segways, etc.) and collective transport will be a mainstay of the urban mobility of the future. To summarize, it is shaped by just a few seemingly simple developmental requirements:

- the realization of a high degree of mobility with maximally economical transport expenditures in the context of density-oriented spatial and settlement planning;
- the facilitation of local mobility by giving planning preference to pedestrian and two-wheel traffic;
- the construction of a correspondingly high-performance infrastructure of pedestrian and cycling routes;
- a planning, design, and political focus on collective transport as a digitally systemic inter- and multimodal mass transport;
- the continued use of autonomous, flexible individual transport resources, such as the automobile, bicycle, or scooter, in the framework of digitally mediated, platform-based usage innovations; and
- the electrification of all transport links and vehicles based on an ultimately regenerative energy production.

With the above as a basis, we must now ask: What does mobility design look like? What tasks and design challenges result from the image of a future mobility that was sketched above?

Thesis 6: Mobility Design Means the Design of Systemic Innovations in Mobility

Since the dawn of civilization, the artifacts, systems, and constructive context of mobility have been key focuses of design intelligence and creativity. According to the social anthropologist Arnold Gehlen, man »would have been unable, with his given biological constitution, to maintain himself in raw nature. His activities, therefore, are aimed primarily at the transformation of the external environment as a consequence of simple organic necessity« (Gehlen 1961: 93). According to this theory concerning the emergence of technology, the development of individual technologies and of entire systems for mastering space can be conceived as attempts to substitute for, disburden, or surpass human organs: »The carriage, the riding animal, relieve us of the burden of walking, and vastly out-do its capacities. With the pack animal, this disburdening principle becomes tangible. The airplane, in turn, compensates for the organic wings we cannot grow ourselves, at the same time far surpassing all organic flight« (Gehlen 1961: 93).

The residence of the human being in the limitlessness of space and the limitations of time provided ample motivation to invent the wheel and—speaking metaphorically—to reinvent it repeatedly, creating an entire arsenal of artificial organs designed to overcome space, with whose assistance the limitations of the human body could be surmounted. This has been especially the case since the inception of modernity, with its particularly emphatic affinity for mobility (Rammler 2001). The methods for overcoming space, the phenotypes of their technologies and infrastructures, represent the most impressive testimony of this radical transformation in the transition to modernity. Mobility was a central field of innovation and design during the first great transformation that led toward the capitalist market economy, as well as during the emergence of the modern nation state, and it is also of fundamental importance for the currently emerging sustainability transformation in what is now a globalized world.

Design can and must continue to play a central role in this process. Against this backdrop of a diverse, sociotechnically networked world, design will need to be conceived to a greater extent than before as the *design of systems and of transformation* for the shaping of complex processes of change. The mobility design of the future will have nothing in common with earlier transportation design, with its orientation toward the private automobile. Whereas now it is solely a question of products, in the future it will be a question of giving form to usage concepts and entire mobility systems; where today everything revolves around styling, it will be a question of function and of an unpretentious straightforward aesthetic of quality; and where currently it is a question of maximum variety and the formation of variants for a growth-fixated market logic, it will be a question tomorrow of nondesign, of de-design, of sustainability, radical resource traceability, and superior material value. In relation to these requirements, mobility design can be conceived as an integrative discipline on the basis of analytical-holistic and conceptual-interdisciplinary collaboration between the engineering, social, and design disciplines. Its task is to develop ideas and to contribute to the design of innovative mobility systems, forms of use, and products.

Exemplifying this paradigm is the Institute for Transportation Design (ITD) at the Hochschule für Bildende Künste (HBK) Braunschweig.[01] In both research and teaching, the ITD went far beyond the pure product design of modes of transport to focus on the design of mobility service provision and research into new mobility systems. The precondition for this was the interdisciplinary structure of the ITD, with research, training, and project work drawing not just on design research, but also to an equal degree on the discoveries of the transport and engineering sciences, economic and futurological research, sociology, and psychology. The focus of work at the ITD was on user experience, which is to say on the human being as an individual, on his or her activities, routines, and needs, which must be taken into account in design work. Design work was centered on function alone, but also on usage and usability. The primary focus was not on the design of products, but instead on sociotechnical courses of action.

01 The Institute for Transportation Design (ITD) was organized and led by the author of this essay as its founding director and manager of the degree program bearing the same name.

Alongside the design fields devoted to products, services, and systems, the ITD was subdivided into five scientific working focuses, in which research and design projects, contract work, and consulting work were bundled together. Each work area was structured in a fundamentally interdisciplinary way, remaining open in relation to other focuses while maintaining a methodological orientation toward a core discipline.

The focus on »design, construction, and innovative material usage,« with its subareas design research, design conception, product construction, materials science, and production processes, constituted the center point of the institute's activities, and was concentrated on the construction and design of future-oriented vehicles, components, infrastructures, and systemic interfaces. In the focus on »Mobility and Society,« the ITD used the methods of the social sciences to analyze user behavior and transportation users, as well as social and psychological factors of influence, but also the cultural trends that influence human mobility as framework conditions. The colleagues working on the focus »Future Research« identified possible scenarios for mobility development, for which they also deployed creative methods from design research. The use of non-fossil-fuel energy sources in transportation was a central topic for the department of »Innovation and Transformation.« The focus here was on questions of technical feasibility and technology acceptance, but also on the social practicability of new technologies and services. Building on an identification of cultural, social, and political barriers and path dependencies, the aim was to identify innovation pathways for a post-fossil-fuel energy and mobility culture. The profile of the ITD was rounded out by a focus on »Human-Machine Interaction.« Developed here were approaches and concepts for the design of human-machine interfaces (driver-vehicle interaction, user-infrastructure interaction). Altogether, the model of a symbiosis between theoretical-scientific analysis and the practical design of future-oriented mobility concepts has proven itself over a period of many years as a fruitful research and design approach. These research activities have resulted in numerous publications, which form the basis for the discussion presented here.

Mobility Design for the Future

Essentially, the question of the mobility of the future is a question of our lifestyles and levels of need, but it is ultimately a question of a different conception of prosperity and happiness, one that will be reflected, finally, in altered patterns of mobility, transport technologies, and settlement and temporal structures. Today's economy of waste and acceleration is a phenomenon of the superabundance of the fossil fuel epoch, and it has made us lazy and extravagant. However, mobility begins in the mind. Ironically, we will only be able to achieve the transition to a post-fossil-fuel culture provided we behave as though it has long since become a reality: as a temporary phase of scarcity which bundles our creative potential and compels us to begin without delay with the sustainable design of our society.

Mobility design is essentially the politics of transformation. If the necessary conversion succeeds with this centerpiece of the modern world, then it will succeed in all other areas of need. Even more important today than research into mobility is its courageous and radical design. We already know enough to act with confidence. In Germany, current levels of technology, competency, and prosperity afford us the necessary leeway. Rather than lamenting the lack of alternatives, it is high time that we use the available leeway to engage in experimentation. We can begin immediately, doing things differently piece by piece, rebuilding Germany into a radical blueprint and model for a sustainable culture.

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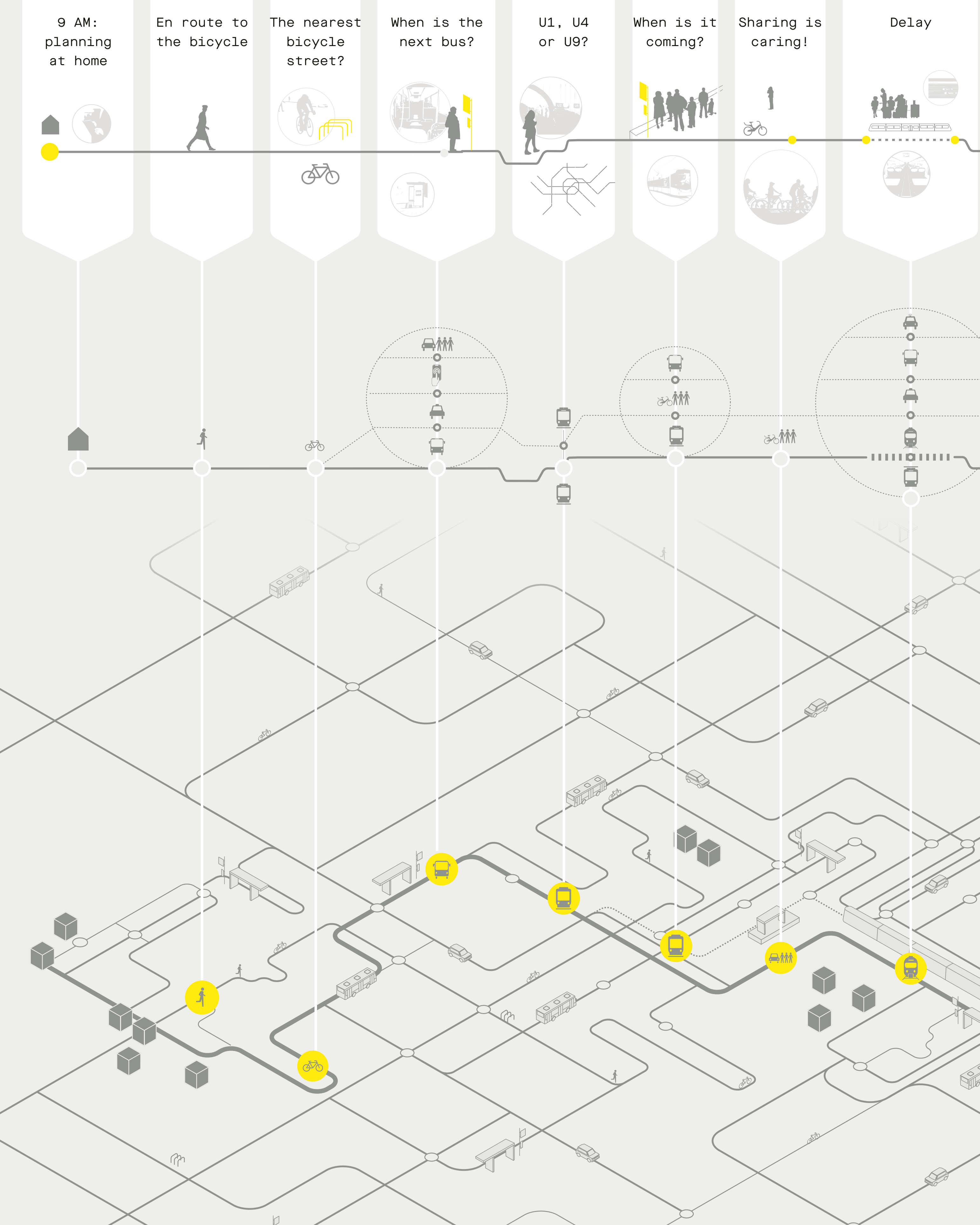
9 AM: planning at home
En route to the bicycle
The nearest bicycle street?
When is the next bus?
U1, U4 or U9?
When is it coming?
Sharing is caring!
Delay


Tuk-tuk
At work
Is there a shuttle service nearby?
Car sharing
Taxi
City train
Autonomous driving
6 PM: back home

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