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Making futures with urban experiments: picturing, preparing and persuading

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Abstract

For city planners, public experimentation has become an attractive tool to “look into the future”, increasingly including novel technologies: Actors test novel mobility options, such as autonomous driving on urban roads to receive real-world feedback on their prototypes; and digital technologies are used to create virtual spaces of experimentation to explore interventions in urban space before implementation. Paying explicit attention to the performative character of experiments and the mechanisms by which they make envisioned futures more plausible than others, we build on the concept of “techniques of futuring” (ToF) to better understand the role of experiments in urban transformations. We ask: How do urban experiments perform mobility futures and how does the performance make these futures plausible? We provide empirical insights on two cases of experimental environments in Munich: a living lab for autonomous driving and an urban digital twin for novel bicycle infrastructure design. We identify three core performative mechanisms by which urban experimentation contributes to making certain futures plausible: *picturing* the vision, *preparing* the city, and *persuading* the public. These mechanisms show how experiments involving novel technologies can become powerful in underpinning the presented visions of future mobility. At the same time, they call for caution when the allure of these mechanisms outplays alternative ways of deliberating and creating mobility futures.

Science highlights

- Explores the connection between experimentalism, performativity, and participation.
- Both virtual and real-world experimentation carry performative authority in making urban futures.
- The concept of Techniques of Futuring (ToF) provides an analytical lens for performative experimental practices.
- Suggests three performative mechanisms that are central in future-making: picturing, preparing, and persuading.



Policy and practice recommendations

- Thinking virtual and real-world experimentation together can lead to better participation.
- A reflexive practice is needed: who has the resources to publicly perform urban futures with experiments?
- Early public involvement in experimental practices is crucial to determine and guide their desired purpose.

Keywords Urban experimentation, Living labs, Urban digital twins, Techniques of futuring, STS, Mobility

Introduction

Different modes of urban experiments are increasingly used to explore future pathways for mobility in cities. For instance, urban digital twins (UDTs) are currently promoted as innovative ways to create what-if scenarios based on urban data. Exploring different future alternatives, UDTs can help “try out” the potential consequences of envisioned measures. The virtual illustration of these consequences allows for new ways of public engagement in planning processes.

With these qualities, UDTs align with a broader “experimental turn” in urban governance and a broader discourse on urban experimentation. They reflect some of the promises that have been attested to living labs and real-world experiments: testing and learning through prototypical implementation to build a more inclusive, integrated, and thoughtful future.

Urban experiments more broadly indicate a shift from the traditional urban planning approach of “predict and provide” to participatory planning practices (Evans et al. 1999; Hajer and Kesselring 1999). The incremental, experimental approach seeks to engage people in urban transformations and has become central in transition strategies, funding calls, and research projects (Laurent and Pontille 2018).

The different ways of transferring and scaling experiments to create impact are a central part of the current transition discourse and under scrutiny (Lam et al. 2020; Torrens and von Wirth 2021; VanHoose et al. 2022). One aspect under discussion is that the possibilities to shape urban futures are not distributed equally. Mobility transformations are often motivated by the goal of more sustainable and livable cities, yet, predominant visions continue to be reproduced, such as the automobile society (Wentland 2020; Mögele and Rau 2020).

In this sense, also experiments potentially render certain futures more plausible than others based on their “performative authority” (Oomen et al. 2022, p. 258). To understand the impact and consequences of public experimentation for sustainable transitions, we analyse these performative activities through the conceptual lens of “techniques of futuring” (ToFs) (Oomen et al. 2022). Hajer and Pelzer (2018) describe ToF as “practices bringing together actors around one or more imagined futures and through which actors come to share particular orientations for action” (p. 222). Emphasizing their performative qualities, this line of scholarship sees experiments not as neutral or inherently inclusive tools, but rather, as coming with built-in assumptions about the needs of specific groups of people that are embedded in their design.

Our research is based on the observation of the emergence of different experimental environments in the urban sphere – in vivo, as experimentation in public spaces, and in

silico, as experimentation in virtual spaces (Laurent and Pontille 2018) – prompting us to explore this connection and to better understand current ambitions to make futures through experimentation. Building on emerging scholarship on ToFs, this article aims to explore the role of in vivo and in silico experimentation in shaping the future of mobility by asking: How do urban experiments perform mobility futures and how does the performance make these futures plausible?

We intend to address the conceptual gap and contribute to this line of scholarship in various ways. We expand work on ToFs by applying this concept specifically to the domain of urban experimentation and empirically trace practices of making futures plausible on the ground. This dramaturgical perspective is needed to deepen the discourse on the performativity of experimentation. At the same time, we see our article as an empirical contribution to strengthening the conversation between different practices of urban experimentation that have been emerging alongside each other in the area of mobility innovation. We explore these questions in two case studies from Munich – a test bed for mobility automation and a virtual experimental environment for new cycling infrastructure. Munich has become one of Germany's hubs for mobility innovation through an accumulation of projects, the resident private companies and research institutions, and the organization of one of the largest mobility trade fairs, the IAA. In the following section, we discuss existing literature on urban experimentation with two foci on material tests and virtual experiments. After the subsequent methods section, we present the two empirical case studies, their narrative, and the dramaturgy of their performance. We discuss these findings and suggest three mechanisms by which urban experiments make futures plausible.

Transformation by experimentation

Cities increasingly use urban experimentation as a governance tool for sustainable transformations (Karvonen and van Heur 2014; Bulkeley et al. 2015, 2019; Evans et al. 2016). Such initiatives aim to try innovations in real-life settings to learn from unprecedented events and processes (Bernert et al. 2023a). For instance, experiments with autonomous vehicles regularly test under which circumstances these cars can drive among other road users (Marres 2020). However, in experiments that include smart innovation and novel technologies, testing is not only happening in urban neighborhoods but is increasingly complemented by computer-aided simulations and modeling, for example, in the context of Urban Digital Twins, in short, UDTs (Dembski et al. 2020; Guckenbiehl et al. 2021; Wolf et al. 2022). More specifically, many urban interventions, such as autonomous vehicle experimentation or the efforts to use and apply more data in the context of smart city agendas, *interweave* “in vivo” and “in silico” testing. Yet so far, social science scholarship has hardly considered them alongside each other to better understand current developments in urban experimentation.

Urban living labs and test beds

To enable a sustainable urban transformation, living labs and real-world experiments intervene and test in public spaces to facilitate social learning and generate knowledge that strengthens the agency of local populations (Caniglia et al. 2021). They bring research institutions, private and public actors, and civil society together to co-create ideas and test them in a real-world context on small scales (Schäpke et al. 2018). The

connection of the experiment to the concrete real-world conditions at the test site facilitates empirical learning from individual settings (Caniglia et al. 2017; Bergmann et al. 2021). The resulting contingency of the local events and reactions is a cornerstone of real-world experimentation (Schikowitz et al. 2023). At the same time, the experimental spaces strengthen local citizens for larger transformative actions (Karvonen and Bylund 2023). For their density and impact on the climate, cities are a particular spot for these kinds of experimentation (Nevens et al. 2013). With a growing number of experimental sites, the mechanisms for generating impact became more essential to analyze how interventions can enable change beyond small-scale intervention (von Wirth et al. 2019; Lam et al. 2020; Sengers et al. 2021). Thereby, experimentation can unfold potential in a more permanently institutionalized form rather than bound to the format of projects (Torrens and von Wirth 2021).

Experiments and test beds widely try out new technologies in societal settings while at the same time researching societal responses and learning about social orders (Engels et al. 2019; Marres and Stark 2020). Hence, we investigate how and with whom they generate new societal visions and understandings (Marres and Stark 2020). With the advent of the smart city, more technical experimental approaches have gained prominence among urbanists (Cugurullo 2018), including practices of “smart experiments” with automation, big data, and sensors (Cowley and Caprotti 2019, p. 428). These experimental practices are embedded within specific contexts, for example, administrative cultures, expectations, and interests of actors who advance different, but not necessarily equally sustainable urban futures (Servou et al. 2022; Bernert et al. 2023a). For example, the visions of mobility in the German automobile sector may diverge from the goals of local neighborhood initiatives. In these contexts, experimentation can be used in different roles for advancing mobility visions (Jung and Wentland 2024). Consequently, real-world experiments and their visions are political and part of democratic ordering processes (Laurent and Pontille 2018). When evaluating the variety of imaginations that materialize in experiments, social scientists should ask “who experiments, what or who is experimented with, who is the audience, and for whom experiments matter” (Laurent et al. 2021, p. 371).

Virtual experimenting and urban digital twins

Laurent and Pontille notice that also digital infrastructures are used to test novel concepts (Laurent and Pontille 2018, p. 91). The movement of *New Urban Science*, for instance, draws on this ambition to apply digital tools and techniques to urban challenges by modelling and simulating complex urban systems (Karvonen et al. 2021). Today we find simulation models of the physical systems of energy grids, traffic networks, and transportation systems, pollution modeling, charging infrastructure, and potential impacts of changes to the built environment. As Leonardi (2010) has sketched, virtual testing presents specific advantages over real-world testing and potentially replaces or complements it. For instance, virtual experimentation, such as in simulations, allows for testing with reduced cost in terms of time, budget, and other resources.

The emphasis on virtual experimentation comes with a set of political implications specific to this setting. This includes politics of representation, as virtual representations are never neutral or self-evident but always selective (Korenhof et al. 2021). Further, engaging with simulation models requires to some extent the “black-boxing” of the

computer program “in order to treat the computer as a unitary entity, and to *interact* with it” (Dowling 1999, p. 265).

The notion of virtual urban experimentation is experiencing an upswing under the banner of UDTs. UDTs, in the broadest sense, can be understood as virtual replications of the city and its assets, comprising objects, subjects, and processes (Guckenbiehl et al. 2021). While the promises surrounding the emergence of UDTs are broad, their benefit for the context of urban experimentation is often emphasized in the discourse: They are portrayed as a “risk-free testing environment” (European Commission 2020), with the purpose to turn “cities into digital test beds for policy experimentation and data-informed decision making” (Raes et al. 2022, p. 8).

Experimentation as a technique of futuring

Both real-world and virtual urban experiments perform imaginations of the future. Visions of the future are a constant object of negotiation and co-exist (Cugurullo 2018) and their experimental enactment impacts future pathways. For instance, Haugland and Skjølsvold (2020) have shown how experiments with self-driving vehicles in Norway shaped regional policymakers’ understanding and policies. Based on this perspective, we specifically contextualize urban experimentation with the conceptual approach of “techniques of futuring” (ToFs): “the identification, creation and dissemination of images of the future shaping the possibility space for action, thus enacting relationships between past, present and future” (Oomen et al. 2022, pp. 353–354). Attending to future-making highlights how experiments connect the present with possible futures. Anchoring these futures in specific visions reduces uncertainty in favor of a particular imagination and a particular suggested pathway. Experiments nudge the public, policy makers, and industry not only to believe and work towards this future but to performing it. However, in contrast to the theoretical perspective of *nudging*, the intervention is not directed to the architecture of minimal choices (Thaler & Sunstein 2008) but entails considerable efforts to make investments into the presented future plausible. We investigate these “practices bringing together actors around one or more imagined futures and through which actors come to share particular orientations for action” (Hajer and Pelzer 2018, p. 222).

Our analysis is structured in two parts, which we derived from the framework of Oomen and colleagues (2022): Relying on two case studies that we consider alongside each other, one on exemplifying the notion of real-world testing and the other of virtual what-if scenarios, we first outline the *narratives* of how the experiments advance their future visions, how the futures make sense in this world and how the form of experimentation connects the future with the present. Second, based on the premise that experiments stage future visions, we elaborate on the *staging* of futures through experiments, how they are presented to an audience, relying on orchestrated interactions and performances that bring actors and materialities together. Through this analysis, we map cross-cutting mechanisms to guide the discussion on what it means to make futures plausible through urban experimentation.

Studying experimental environments in Munich

This article builds on research we conducted on two distinct environments for urban experimentation in the Munich mobility innovation ecosystem: a test bed of autonomous driving as a real-world environment, and a UDT as a virtual environment. Our

qualitative, interpretive approach is rooted in Grounded Theory (Charmaz 2006) and case study analysis (Yin 2018). This approach allows us to empirically explore two variations of experimentation. Their mutual investigation allows us to sharpen our understanding on the role of current practices in urban experimentation and their implications for making futures plausible, and to develop shared mechanisms for broader discussion. In the analysis, we paid particular attention to discursive storylines as well as to materialities, technologies, and actor constellations to go beyond processes of policy decision-making (Servou 2019).

Case selection

To investigate the ToF of experimentation in the urban context, we analyze two projects in Munich, Germany: the living lab “TEMPUS” and virtual platform “Digitaler Zwilling Munich”, Munich’s UDT. Both are regularly used as references for the region’s mobility development. Munich’s city administration has been promoting both projects serving as experimental environments to try out and get an impression of urban interventions before (potential) large-scale implementation. This way, city planners, innovators, private companies, and researchers seek to better govern mobility development.

TEMPUS is Munich’s test bed for connected and automated driving. The project was a central step for the City of Munich to introduce self-driving vehicles with priorities of safety and efficiency. *TEMPUS* created a large test bed in the Munich region and experimented with different scenarios of automated driving to learn about the interaction of autonomous vehicles and pedestrians. Further, the project organized events and showed public presence to engage citizens in discussions about what a safe and comfortable automated future of mobility should look like. After the project period, the test bed remained an experimental ground for actors in autonomous driving. *TEMPUS* won the German Innovation Award for Living Labs in 2022 (BMWK 2022).

Munich’s UDT program is a lighthouse initiative of Munich’s digitalization strategy to virtually experiment with urban futures. The UDT is envisioned as the “digital heart” of Munich, comprising its various digital resources, including data, models, and visual outputs, amongst others. Early work has been focused on use cases for mobility and climate-resiliency, and has been progressing to other themes, including other urban domains, public participation and knowledge-transfer. Next to the promise of providing a better data basis for decision-making or improving administrative processes through a common infrastructure, it has specifically been promoted due to its potential to create what-if scenarios. The UDT, as a virtual representation of the city, is presented as a virtual environment to test, simulate, and visualize what possible future states of the city might look like. As described in a promotional video, not only can stakeholders simulate and analyze different future development alternatives to select the optimal solution, but present and visualize them in an accessible way (München. Digital. Erleben. 2021). Through such a comprehensible presentation, the digital twin is supposed to facilitate public participation.

Data collection and analysis

We collected empirical data through semi-structured interviews, document analysis, and ethnographic observations. The interviews on *TEMPUS* (11 interviewees) and *UDT* (15 interviewees) were conducted in 2023 and 2024. All direct quotes from the

interviews are translated by the authors. Through our position at a Technical University within the mobility innovation ecosystem in Munich, we could enrich our data collection by extensive participation in the field, such as events, meetings, or public demonstrations of mobility innovations at which we took ethnographic field notes. The data of the cases was coded with qualitative data analysis software.

How two experimental environments make their futures

TEMPUS

Narrating future mobility with a test bed

The City of Munich is gearing up for autonomous driving. To become a vanguard of automated mobility, the experiments within the project TEMPUS should provide comprehensive insights for the city government. In their newly created test bed, the project partners experimented with infrastructural upgrades and interactions between citizens and autonomous vehicles. Conversely, having such a test bed, the city incentivizes industry to come to Munich and test their automated driving functions. The project aims to enable automation and digitization for a “safe, sustainable, and comfortable mobility for all Munich citizens” (TEMPUS 2022). While the promises of safety and efficiency draw on the general promises of autonomous driving, TEMPUS investigates how these visions can be realized in Munich. In particular, the project planned to advance the automation of public transport, the safe operation of autonomous vehicles in complex junctions, and the efficient steering of traffic flows in cases of special events. Therefore, TEMPUS tested how to communicate between cars and infrastructure because safety in autonomous driving depends on the available information about the environment. The partners equipped the junctions in the test bed with roadside units and little boxes at the posts. They can exchange information about the traffic situation with an approaching vehicle for a better overview. This data connection can further phase the traffic light according to the need for ambulances, which was another use case at the test. The efforts resulted in a guideline that should enable other districts and municipalities to set up infrastructural technologies. They can test how they can introduce autonomous driving functions. This way, the city can get a head start: “If automated driving comes and needs such a technology, we want to be prepared” (I1). Since the test bed stays in place in the future, companies can continue testing their autonomous driving functions, primarily enabled by the experiments. As the second mayor of Munich put it, “The TEMPUS project is for us a look into the future of mobility” (TEMPUS 2022). The experiments are not only an outlook, but the detailed experiments with technologies lay out the necessary steps on the path from the present to an autonomous future. The quotes underscore this narrative and the importance of the test bed for learning about pitfalls in the process of implementation.

Autonomous driving is also said to improve the efficiency of public road spaces. The tested vision considers autonomous driving merely a technology for public transport and shuttle services. This vision was presented at a panel on autonomous driving in Munich when a researcher suggested that the city would only need a fraction of vehicles if autonomous shuttles replaced private car travel (F1). While this vision could only be calculated in simulations, experiments on public transport automation were considered obligatory to gain relevant insights on how to approach this vision. The real-world experiments were seen as proof of the viability of the visions of autonomous driving.

At the same time, there is little discussion of how these goals could be reached otherwise. Throughout the project, the team emphasized that it is essential to “take people with you” instead of simply releasing a technology on the road (12). At the IAA 2023, the visitors appreciated this strategy to participate the people in streets rather than mainly focusing on the technology¹.

Staging future mobility with a test bed

TEMPUS actively introduced people to the new technologies as part of the experimentation. Researchers tested how citizens reacted if an autonomous car turned to the right in front of them. The idea was to learn more about the interactions between vehicles and pedestrians. Since the test cars were not available for an autonomous maneuver, the researchers built a mock-up autonomous car and conducted so-called Wizard-of-Oz experiments. In these experiments, the vehicle appeared to be autonomous from the outside while it was steered by a human driver, disguised with reflective materials in the color of the seat. Further, a rack with sensors was mounted on the top of the car to make it look like an autonomous vehicle. The intersection was prepared with cameras and signs that informed people about the recording. In this scenario, the pedestrians crossed the street while an autonomous car waited to turn right after the pedestrian. Then, a researcher approached the pedestrian to ask whether they noted something unusual or how they assured that the vehicle stopped and let them cross. This scenario was thoroughly planned and prompted the pedestrians to explain the encounter with the technology. The junction became a stage for a pretended autonomous future, waiting for the reaction of its audience of pedestrians. There was hardly resistance to the tests, a high number of pedestrians participated in the subsequent interview.

On other occasions, participants were actively invited to focus groups, complementing the encounter on the street. The project followed the project team’s plan to reach out to society and bring different parts of the population into conversation about autonomous driving. They organized focus groups with children, older adults, and people with reduced mobility to collect the voices of groups that are often overlooked in technology development. The project was intended to provide an opportunity for these groups of people to express their fears, concerns, and requirements. At the beginning, the focus group participants were given an explanation of autonomous driving and shown an informative video. Then, the facilitators opened the discussion on questions like how the interaction between pedestrians and autonomous cars could be, what is essential, and how they think about it. These participatory events indicate a degree of openness towards a future of autonomous driving and allow for voicing concerns and dissent. Further events followed: TEMPUS presented at the Munich Mobility Congress and had a prominent stand at the International Motorshow Germany in Munich between famous car manufacturers. The circumstance of having implemented the large test bed in Munich allowed them to deliberately reach out to the public and discuss autonomous driving as a plausible real-world scenario.

While these stagings of the autonomous driving vision entailed a public audience, much of the material set up was hardly visible due to the small size of the grey boxes at larger junctions. The project communicated the infrastructural changes in posts on their

¹ <https://tempus-muenchen.de/iaameinungsumfrage>.

website and tried to provide a picture showing the technology in action, which was challenging due to the invisibility of the infrastructural equipment. Yet, these material ways of developing mobility futures by testing how an infrastructural technology works are central to TEMPUS preparing the city for an automated mobility future. The involvement of central mobility actors in the city ensured that the experimental activities would continue in follow-up projects. In particular, another project focuses on the automation of public transport, building on the insights of TEMPUS (Stadtwerke München GmbH 2024).

Digitaler Zwilling München

Narrating future mobility with a digital twin

Beyond the promise of providing a better data basis for decision-making or improving administrative processes through a common infrastructure, the UDT has specifically been promoted as a virtual environment in which to test, simulate, and visualize what possible future states of the city might look like, allowing actors to “look [...] to the future: in ten years, what will Munich look like?” (I3). This promising narrative is part of the rationale behind the city’s efforts to build the UDT.

Potential is seen above all in the ability to present, try out and evaluate different, alternative futures before a decision is made. For instance, if the city planned for changes in the built environment, creating simulations within the environment of the UDT could help investigate the impact on traffic flow, noise or particle emissions of different alternatives: “[...]if you now have a digital twin where you could play through different alternatives, what-if scenarios, then you can make better decisions afterwards in order to reach your goal more effectively” (I4). The quote expresses the value attributed to ‘trying out’ potential future visions. With the comprehensive database that the UDT is grounded upon, actors envision that these what-if scenarios can be examined across domains, for example, connecting traffic and air quality.

What is special is that the UDT is not only used to simulate and analyze various future development alternatives to select the optimal solution. As described in a promotional video (München. Digital. Erleben. 2020), it enables the city to “share information quickly and transparently, presenting and discussing different possibilities and options thanks to the visualization component of the digital twin”. Due to its potential to visualize facts in an easily understandable way, the UDT is often presented as a tool for communication and public participation.

Indeed, one of the most prominent applications of the UDT in Munich to date focuses on its visualization capabilities. The UDT has been used to create visualizations to support the public communication of the political decision of the “Radentscheid”: a citizens’ referendum to restructure public space in favor of bicycle infrastructure. Using the UDT, 3D representations of the street space at stake were created. One representation showed the selected streets in their current state, and another visualized the hypothetical future street as if the referendum was implemented. In a video, both 3D visualizations were placed side by side.

In addition to the improvement and construction of cycle paths, e.g., wider design or better visibility, these developments are politically linked to Munich’s larger ambitions for the future: more green space, biodiversity, urban cooling, water management, and unsealing, as expressed in the following quote: “You could say that it’s great because it

also promotes greenery in the city and shows once again how the city can look different. With more trees, of course. For climate adaptation” (I5). The quote indicates that a specific vision of the future is presented through the UDT, materialized in the demands of the referendum, implicitly pointing to the performative capacity of portraying certain aspects in a visual, compelling way. This emerges as particularly powerful as the present and planned city are staged directly next to each other in the visualization. Although UDTs offer the possibility of carrying out detailed models and calculations, in this exemplary case the UDT is rather used to convey a broader direction or a more conceptual understanding of the future and what-if scenarios – e.g., a narrative of more greenery or safer biking – to communicate with the public.

Staging future mobility with a digital twin

Most actors agree that a huge benefit and potential of UDTs is the specific way in which they allow to convey scenarios, impacting the opportunities to stage potential future visions. The UDT team was awarded second place in the German Cycling Award 2022 in the category of citizen participation for these visualizations, as the city administration uses them to communicate the plans to the public (Landeshauptstadt München 2022)². On the one hand, being based on a citizens' referendum, the visualizations are directly supporting a successful mechanism of participatory governance; on the other, the implementation is accompanied by an ongoing public debate in which opinions on the “right” distribution of public space, specifically between private car and active mobility, clash.

The interviewees particularly emphasize the value of 3D visualizations for public communication:

They created a digital 3D model of the current situation and the planned situation, which visually shows how a replanning would have a positive effect for cyclists in the area. When something like this was done in the past, it was of course primarily done with analog 2D plans, which can certainly give a first impression, but in this case, they went ahead and visualized both scenarios in parallel in a game engine, took a fly-through of these two scenarios, and showed it at a public information event. And the response was very positive in terms of the advantage of this three-dimensional 3D visualization, which is that you can get a much faster and more intuitive impression of what such a reconstruction project would actually look like in real life (I11).

They assume that 3D visualizations are easier to understand, convey their meaning much more quickly and create better access to what will change with the proposed redesign of urban space. Another interviewee emphasizes the potential of immersive technology, such as VR or AR. Regarding politics, he adds: “An image says more than 1000 words” (I7). Based on the bird's eye view video “flying” over the streets in the virtual 3D visualization, you “see how it changes and how, for example, the footpath and cycle path are clearly separated, and you simply recognize the higher level of safety” (I7). The actors here not only emphasize the general value they see in visual representation, but also point to advantages that for instance real-world testing lacks, such as zooming out to larger scales and gaining an overview. The UDT becomes a stage for the future in various dimensions. Accordingly, UDTs provide experiences of the future mainly in multimedia

² An example of such a video can be found on the Youtube Channel of Munich's Mobility Department (München unterwegs 2023).

settings. Screens and VR technologies offer the possibility of merging future scenarios with experiences of the real world. The above-mentioned videos, which virtually show the planned bicycle infrastructure in 3D, are used in citizens' meetings.

Regarding one of their first experiences with using these 3D visualizations in a public participation setting, one interviewee recounts: "So, no matter VR, or on the screen, they [the citizens] could see exactly what it would look like in the future if we went for this plan. And then we had a completely different experience (I8)". This would enable a level of understanding, engagement, and acceptance that was not possible before, "an entirely different basis for discussion" (I8). These days, all citizen meetings in the context of the "Radentscheid" are conducted online, so that the videos can be included in the presentation and are usually appreciated as a "super clear presentation" (I6). Indeed, interviewees reported that they received positive feedback in the citizen meetings and that the participants appreciated this novel way of presenting information.

Experiencing the future through 3D visualization or immersive technologies, presumably enabling recipients to "get a feeling of what urban space could look like" by speaking to people "on an emotional level" (I) promotes an idea of an intuitive understanding that is connected to the assumption that thresholds for participation are lowered. At the same time, these quotes illustrate how belief in the superior qualities of visual representation appears almost taken for granted. Further research with citizens is required to understand in which ways these technical opportunities do really facilitate meaningful participation. In the specific context of the "Radentscheid", the visualizations mainly seem to function as tool for information rather than the basis of an open dialogue which is also due to the rather late project stage in which they have been employed.

Making futures: picturing, preparing, persuading

Both modes of experimentation have in common that they promise a "look into the future" and present desirable futures for at least some residents (Engels et al. 2019). Claims towards participatory opportunities are precisely what distinguishes the UDT from other types of modeling and constitute a central aim of test beds. To bring citizens on board, these futures are embedded in public settings – the real-world test bed or the virtual representations in citizen engagement activities. This staging of future visions incorporates ideas of (re)presentation, public demonstration, and communication (Laurent and Pontille 2018).

Thus, narratives of both experimental environments emphasize the potential to open public discussion. Yet, the practices of engaging the public in the portrayed cases speak to a particular way of participation: Citizens are consulted for their opinions; they are informed about the city's strategy and vision and the actual impact of the citizens' comments remains to be seen. The orchestration of their involvement echoes the observation of STS scholars that participatory events are mobilized to establish acceptance and realize a planned innovation in ever shorter time frames rather than facilitating a more open debate about how we want to live in our cities (Delvenne and Macq 2020). To some extent, the test bed as material experimental environment and the UDT as virtual experimental environment are themselves put to the test regarding their capabilities to bring people on board for urban development. This can be seen in a survey TEMPUS planned to compare the increase of awareness about autonomous driving among the test bed residents and in the UDT's continuous tinkering with new formats and functions. In

different words, our cases are at the same time experiments *with* governance tools, the experimental environments, and experiments *on* governance (Bulkeley et al. 2015).

The two modes of experimentation work as complementary governance tools due to several differences. The participatory range of the test bed includes uninvited participation; people entering the test bed can encounter the autonomous driving future without knowing, sometimes even without noticing. Yet, due to the material and financial constraints of a prototypical implementation of AVs, the temporal scope of the tests and number of autonomous driving tests remains small compared to the possibilities of virtual experimentation being able to simulate traffic flows in broader temporal and geographic scopes. The simplicity of expanding scale in the virtual tests, the low risk of causing harm and the cheap way of transforming – virtually – vast areas of infrastructure, make the UDT an attractive tool for communication strategies. However, the UDT mediates the experience of the future through digital devices, whereas the team of the test bed values the immediate encounter of the public with potential novel mobility.

Both modes of experimentation share a powerful performative capacity in making futures plausible (Oomen et al. 2022). The presented futures may build on regional path dependencies and thereby limit the imagination of alternatives. Following the hype of a smart city, technology-centered experiments with automated and digitized forms of mobility are often advertised as transformative sustainable urban futures, while simultaneously demonstrating conservative regional innovation approaches that preserve existent mobility paradigms (Pfothenauer et al. 2023). Hence, the practices of future making render visions powerful and deserve critical reflection in urban experiments and transdisciplinary research. In the following, we reflect on the implications of these practices through the lens of three mechanisms that we develop as characteristics of (urban) experiments as ToFs.

Picturing

Urban experiments make ideas visible. Advanced visualization techniques play an important role in creating both real-world and virtual experimental environments. The presentation at the German Motor Show allowed visitors to see the automated vehicles with their own eyes. The UDT made the imagination of potential futures accessible through visualization and digital methods. As one interviewee stated: “Now we have the opportunity to use digital planning tools to create scenarios and make forecasts and simulations. So that you can also involve citizens at a very early stage” (I9). Seeing an autonomous vehicle was a conversation starter for many people involved in the experiments and a reason to express concerns and attitude towards the technology that became tangible. The UDT was used to visualize the planned reconstruction of the street and provided a feeling for the overall appearance far before entering the construction. Engaging with the public, temporality is key and the early stages of change processes provide the opportunity to take public’s opinion into account (Felt 2016).

Notably, picturing the envisioned mobility futures is characterized by a coherent depiction, fully working, as if this future was already possible. As viable scenarios, the visualizations obscure technical and social uncertainties. In the case of TEMPUS, the public experienced an autonomous driving technology that in reality is not “ready” yet for full deployment. The seemingly autonomous car is steered by a hidden driver in a Wizard-of-Oz experiment. In the UDT case, the new bicycle lane is presented on a

screen, recognizable within its actual location, existing in parallel to its not-yet materialized state. Preselected and scripted, the coherent presentation of the visions takes precedence over creating experimental knowledge with open-ended outcomes. In clean visuals, the messiness and the consequence for social routines is hardly graspable and also the technical functionality is not necessarily a prerequisite to picturing what looks like a coherent and glitch-free future. Pictures of the future might be more contested than these municipal initiatives show. For example, incumbent actors render widespread visualizations for futures of autonomous vehicles that problematize car-unfriendly environments, which urges policymakers to reflect on the implications of circulating depictions of the future (Martin 2021).

Preparing

Public experiments contribute to building collective imaginations and multiple ways of learning for transfer and larger implementations (Bernert et al. 2023b; Metzger et al. 2025). But they also prepare the future by defining standards, developing material prototypes, and plans. Haugland (2023) notes that experiments preconfigure futures through the ways they approach their ends, and that projects with less rigidly defined targets tend to offer a more open approach that can adapt along the way to the emerging politics of transformation.

The urban experimental practices mobilize resources and collectives around mobility visions. TEMPUS installed and tested communication systems at various junctions in the test bed. To upgrade the infrastructure, all these junctions needed to be digitally mapped, which had never been done before in this detail. Learning how to map the myriad layouts of junctions for a smooth technological upgrade can be seen as a crucial preparation for a larger roll-out of autonomous driving. At the same time, the joint initiative brought together central mobility actors and authorities in the region to think whose competences are needed to rebuild urban mobility across city and suburban districts. The evolving trust and collaborative spirit laid the groundwork for future implementation of autonomous driving. The UDT, in turn, can be understood as a broader effort to set up long-standing data infrastructures and resources along with administrative processes that allow for easier access to integrated knowledge about the city and visualizations in governance processes. Decisions could be made better and faster, paving the way for physical intervention in a more efficient and controlled way. In preparing futures, the experiments go beyond the dramaturgical domain and set not only the stage but also a foundation for an expansion and practical implementation of tested visions.

The material preparation implies the viability of the tested future and legitimizes further material interventions in the present. In the case of the test bed, the preparation of the future is broken down into smaller steps and technological functions. One experiment concerned digital systems for the automated prioritization of ambulances at traffic lights, while another dealt with the automation of a public transport bus. The incremental preparation is particularly well-suited to technologize mobility in the future. In contrast, the bike-lane visualizations through the UDT convey a broad concept of a long, large-scale infrastructural transformation. The visualizations allow a literal glimpse into future states. Through these demonstrations and the opportunity to see them with one's own eyes, they become more imaginable. In

setting the present and future visually next to each other, as done in the videos for the “Radentscheid”, both timelines are brought into a relationship. This type of presentation can be understood as actionable: not only does it suggest that a future is possible, but it also implicitly instructs us on how to move there from the present.

Across both modes of experimenting, the ToF expresses that those various futures can be tried out in a tentative, safe environment without touching the actual city. In this narrative, it is the exploration of potential futures that will enable users to identify the best option efficiently. Virtual tests are often considered a step prior to moving the tests into the “real” world (Grieves and Vickers 2017). As one interviewee explained, the UDT is “very large playground to test new technologies, and to just simply, show *that* it works” (I10). Like a proof-of-concept, the fact that the future is virtually graspable is staged as confirmation of its later materialization.

Persuading

In our cases, the experiments leave no doubt about the societal benefit of the demonstrated visions. They present their approach in line with the public good and generate a persuasive moment when showcasing the next steps towards this future. We argue that this third mechanism of persuading is mainly a discursive strategy. The actors involved consider the tested visions as worthwhile investments, and the staging of the experiment provides an opportunity to convince the public of the same. These efforts are targeted to create collective visions, become a plausible shared imagination of a better future for a larger, regional public (Hilgartner 2015). For instance, at a public mobility event in 2023, the presentation of the TEMPUS results was preceded with the announcement that Munich could save up the space of hundreds of thousands of cars if it replaced all private vehicles with autonomous shuttles, while maintaining the same transport capacity. The visualizations of the bike lanes are presented through technologies that are considered attractive in themselves and show pleasant environments with great weather and a lot of greenery. One interviewee mentioned that these visualizations are helpful in showing that the future is “nicer” than the present, intertwined with the idea of using visualizations, VR and other technologies as an attractive form of representation.

In the two cases analyzed here, we can assume that the actors who put a lot of work and resources into creating and staging these futures believe that they are generally positive and would like to persuade others of this impression as well. As STS research has shown, persuasive narratives that present socio-technical futures as a matter of time already preconfigure the imagination in this way (Bareis and Katzenbach 2022). This is particularly evident in cases that are considered socially controversial. In the case of the bike-lane visualization, for example, actors assume that the visualizations can convince critical people that the presented future is not that bad, even if they might initially oppose it.

Conclusion

Urban experiments put curated visions to the test (Marres and Stark 2020). We suggest that their performative dramaturgy deserves more attention as powerful techniques to shape urban futures (Oomen et al. 2022). We explored two experimental environments of current relevance – the autonomous driving test bed TEMPUS

(in vivo) and the UDT with its visualizations for a citizen referendum to improve bicycle infrastructure (in silico) – to show how different kinds of technologized, urban experiments are used to build, narrate and stage urban futures. Thereby, urban experiments offer a prime empirical avenue to expand the theoretical concept of ToFs, providing new inroads into a better understanding of the entanglement of experimentalism, performativity, and participation. Specifically, we highlighted three mechanisms for a better understanding of how experiments make futures plausible.

Building on the performative authority of scientific experimentation, public experiments in transition governance suggest the generation of knowledge, methodological legitimacy, and openness in its outcomes. Ideas of urban experimentation are often accompanied by the promise that the public will be able to participate in such processes at earlier stages. Yet, our analysis shows that experimenting with future mobility is not primarily a method of open-ended knowledge production. The performance of the future from a powerful standpoint generates lock-ins (Bareis and Katzenbach 2022). The experiments discussed above embodied certain visions that are not completely up for debate but already pave the ground for their realization. This pre-configuration at the junction of science, industry, and policy resonates with recent scholarship on a capture of future visions (Hajer and Oomen 2025). In particular, in the local mobility context of Munich, this aspect warrants attention; it is characterized by frictions between governance on the City and State level, a powerful automotive industry, and a notable juxtaposition of car vs. bicycle mobility in the public discourse. In our cases, the actor constellation suggests that the means to perform mobility futures and portray them as viable and desirable are not distributed equally.

Considering the practical opportunities for participation, the ToF perspective, too, comes with limitations: by focusing on how stakeholders, and typically those who are authorized and powerful, perform futures, the analytical lens of ToFs may be even more blind to subversive voices, unsolicited forms of participation, and failed futures that never reached any kind of public stage. Furthermore, a better empirical understanding of how a specific ToF actually contributes to the materialization of a particular future is still lacking. It is an endeavor that is anything but simple, not least because of the temporal dimension involved.

Our findings raise the question of how much leeway there is for public participation, alternative visions and contradiction. While we mainly consider the above cases analytically as a way to understand the impact and consequences of experimentation and its performativity, our research offers opportunities for institutional learning also beyond our empirical context. Hence, we suggest a reflexive practice of performative mechanisms. We hope to steer the discussion of urban experiments towards questions of who can experiment and of who has the power to create performative authority (Oomen et al. 2022). Based on our empirical observations, we find that both real-world and virtual testing hold significant promise for public participation, especially when these formats are constructed as contexts in which not only the future under experiment is discussed but also what makes an urban experiment meaningful to the public in the first place. A reflexive practice of who uses the

stages for future visions in what ways can contribute to better public experimentation as a tool to govern urban transformation.

List of quoted interviews

I1	2024	Interview City Administration
I2	2023	Interview City Administration
I3	2023	Interview Start-Up Partner
I4	2023	Interview University Researcher
I5	2024	Interview City Administration
I6	2024	Interview City Administration
I7	2024	Interview Politician
I8	2023	Interview City Administration
I9	2024	Interview City Administration
I10	2023	Interview Private Sector
I11	2024	Interview University Researcher
F1	2023	Fieldnotes Mobility Conference

Abbreviations

UDT	Urban Digital Twin
ToF	Technique of futuring

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Author contributions

This article was a close collaborative endeavor of three authors within their research group. All authors (MJ, SK, MM) equally and substantially contributed to conceptualization, analysis, interpretation of data, and writing. SK collected the data for virtual experimentation; MJ and MM collected the data for real-world experimentation. All authors have read and approved the final manuscript.

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Data availability

Respecting privacy agreement between researchers and participants, data will not be shared.

Declarations

Competing interests

The authors declare no competing interests.

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