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Towards hyperreal planning? Surveying practical uses of digital models and simulations in Hamburg's public administration

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ABSTRACT

As urban planning practice increasingly intersects with digital technologies, models and simulations are becoming central components of integrated urban development. Yet, claims that such tools either risk a return to technocratic planning or support better decision making are often made in the absence of empirical evidence on their institutional uptake and practitioner's needs. This exploratory survey addresses this gap by examining which models and simulations are employed by the public administration of Hamburg, Germany, and for which spatially relevant decision-making processes. The analysis also investigates which models and simulations are desired for future integrated urban development purposes in the context of an urban digital twin. Findings indicate that while around two thirds of the currently used digital models are static representations of urban systems – such as data layers and 3D-models – the majority of requested models lie in the domain of dynamic simulations for mobility, the urban environment, and urban development. This suggests a pending shift from static to dynamic representation. Moreover, results highlight that sharing a pluralistic set of simulation models across departments could harness substantial synergies. Consequently, the study argues for public digital infrastructure capable of embedding computational advances into multi-stakeholder planning processes.

KEYWORDS

Urban digital twin; modelling and simulation; public administration; integrated urban development

1. Introduction

Urban planning practices are changing in the wake of ubiquitous digitization (Potts 2020). In a European context, dominant frameworks like the New Leipzig Charter emphasize the key role of digital technologies, specifically the usage of big data within public data infrastructures, to advance integrated urban development. On a policy level, the EU's 'twin transition' (Barbero et al. 2025) links digitization and sustainability goals, essentially positioning the former as a means to realize the latter. At a local level,

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cities and municipalities take up the twin metaphor and start to develop their 'digital twins' for various purposes, including sustainability and resilience (Batty 2024; Therias and Rafiee 2023). However, predominant epistemological, ontological and methodological underpinnings of the ongoing paradigm shift have yet to emerge as the large-scale implementation of technologies progresses (Potts 2020).

Integrated urban development – supported to various extents by digital technologies – takes place on a multitude of levels: between different planning domains, different scales, different procedural requirements, and different planning horizons (Beckmann 2018). Conceptually and legally, city administrations are tasked with integrating objectives across departments, stakeholder groups, and sectoral interests (European Commission 2020). In every city, this process results in unique multi-level governance structures with formal and informal rules influenced by local, regional, national and international guidelines, specific politics, and various degrees of connections to actors outside the core city administration.

Scholars of multiple domains summarize these oftentimes messy and opaque procedures somewhat neatly as 'decision making' and suggest that their domain-specific models are capable of improving integrated urban development. Specifically in the field of smart cities, researchers develop an increasing number of computational 'solutions', simulation models, and tools (Fabolude et al. 2025; Miller 2018; Pejic Bach et al. 2019; Teutscher et al. 2025). Historically, such work has encountered little practical attention (Pettit et al. 2018) and planning relies on 'perpetuated traditional methodologies on new devices' (Potts 2020, 282). This is attributed to cultural barriers on the side of planners (Geertman 2017), a more general notion of the failed promises of technocratic planning (Cardullo and Kitchin 2019) and a mismatch between the practitioner's needs and the tool's affordances (Pelzer et al. 2014).

The recent interest in urban digital twins however gathers attention of researchers and city officials alike (Therias and Rafiee 2023) and can be interpreted as a new link between theory and practice for integrated urban development (Batty 2024). With a specific priority on analytical urban models and dynamic 'What if?'-scenarios, urban digital twins heavily focus on large-scale simulation models to address planning challenges in multi-stakeholder settings. Some planning scholars caution about a regress to positivistic planning paradigms (Hersperger et al. 2022) while others point out the potential for co-produced platforms that allow for experimentation with novel participatory, self-organizing means (Kleinhans, Falco, and Babelon 2022; Potts 2020). However, at the nexus of planning sciences, computational urban science and public administration research, there are little to no empirical studies addressing the institutionalized usage of models and simulations for spatial decision-making procedures. We argue that such evidence is needed for three main reasons. One, it provides empirical insights to assess in which direction the ongoing paradigm shift is heading. Two, it informs the normative debate about how we ought to plan in the future. Three, it enables researchers to better align planning support systems such as urban digital twins with practical needs.

To help bridge this gap, this study explores both the status quo and future potentials of using digital models and simulations in decision-making processes of the public administration. We select Hamburg, Germany, as our city of study since its legal status as a German city–state enables a multi-layer investigation and it pursues ambitious digitization efforts for its administration. Hamburg has in the past actively promoted multi-stakeholder experimentation for digital planning (Raven et al. 2019), has set up a publicly managed, open-source data infrastructure (Tegtmeyer et al. 2022) and is currently the leading German city to develop urban digital twin standards and technology for integrated urban development.

The following two research questions guide our research: Which models and simulations are currently used by Hamburg's administration for spatially relevant decisions? Which models and simulations are wanted by the administration in the future for which purposes of integrated urban development? To answer these questions, we use a novel two-stage data collection process, combining an online questionnaire with an interactive web tool and a physical sensitizing package for recipients.

We structure this paper as follows: First, we lay out important groundwork on integrated urban development, planning support systems, and modelling and simulation for public decision making. Second, we describe our methodology and the participant selection. Third, we present our findings. Lastly, we discuss the findings in the context of the emerging digital twin paradigm and conclude with future research avenues.

2. Background

The complex adaptive properties of cities have brought forward various paradigms to plan and manage their development. In Western planning theory, after decade-long modernist master planning and technocratic analysis of mostly physical urban systems, the inherently social production of space became institutionally recognized towards the end of the 20th century (Taylor 1998, 16ff). With the 'communicative turn', new processes and methods were designed to integrate technical and local expertise for a co-production of planning knowledge (Healey 1992). With what Kleinhans, Falco, and Babelon (2022, 771) describe as a 'consolidated paradigm shift', framework documents and guidelines by large-scale institutions such as the UN's New Urban Agenda, the Sustainable Development Goals or the EU's New Leipzig Charter presently proclaim the integration of social, economic and ecological goals with participatory means. The New Leipzig Charter, adopted by the EU's ministers responsible for urban matters in the year 2020, specifically calls for a multi-level integration of spatial scales, policies, participatory approaches and the three dimensions of the just city, the green city and the productive city (European Commission 2020). All planning frameworks and policy documents position digital infrastructure as a key pillar of sustainable and integrated urban development (Barbero et al. 2025; European Commission 2020). However, scholars at the same time caution against a regress to positivistic approaches with digital means (Potts 2020) and identify a 'a great need for further research […] to avoid an unreflective shift towards technocratic planning practices' (Hersperger et al. 2022, 2537).

In the digital realm, practices of integrated urban development inevitably rely on some sort of digital model. Digital models can be defined as formalized computational representations of a natural system (Rosen 2012) and generally distinguished into static and dynamic models (Guala 2002). While static models formalize properties of a system at one point in time (e.g. a 3D-model, a registry of city trees, etc.), dynamic models describe the behaviour of a system considering the change of one or more index variables (e.g. land use interaction models, transportation models, wind models, etc.) (Nance 1981). Dynamics models are prerequisites for simulations, which can be broadly defined as imitations of 'one process by another process' (Hartmann 1996, 83).

In academia, there is a long history of developing models to find patterns behind urban phenomena, better understand and describe cities, and inform policy. For a non-exhaustive overview see e.g. Arcaute and Ramasco (2022). Analyzing the transfer of some of the most influential urban models to practice, Cottineau et al. (2024) find that a model's uptake is influenced by its focus and simplicity, transparency in noting assumptions and its 'transportability'. For the latter, they identify a tradeoff between a model's formalization type and its circulation in policy and academia: While a mathematical formalization is beneficial for a model's uptake by other (largely quantitative) scientific domains, it hinders its circulation in the qualitatively coined planning and policy domain (Cottineau et al. 2024). This might also be the case with integrated land-use transportation models: Miller (2018, 390) find that although there are many scholarly endeavours, they generally 'have failed to achieve widespread adoption' in cities. Similarly, the system dynamics paradigm is increasingly used by academics for modelling and better understanding urban systems (Fabolude et al. 2025) but also lacks practical uptake and stakeholder engagement (Pejic Bach et al. 2019).

In planning practice, the focus is less on dynamic models of large-scale urban systems, but rather on evaluating or generating concrete planning variants with the help of geoinformation systems (GIS), city information models (CIM), planning support systems (PSS), and other technological tools. While differing in their specific design, such spatial analysis tools are mostly static in nature. If present, simulation capabilities largely refer to a user manually altering data to 'simulate' changes in the built environment and then conducting spatial analysis (Degkwitz, Schulz, and Noennig 2020). Although the field of planning support systems also continues to grow in terms of scientific metrics (Daniel and Pettit 2022), scholars make out an 'implementation gap' regarding practical uptake of such largely static representations (Geertman 2017; Pettit et al. 2018).

Considering this apparent gap between theory and practice, it seems worthwhile to ask why growing academic fields of both PSS and dynamic simulations are met with little uptake from planners and practitioners of integrated urban development. While some scholars attribute this to inherent flaws of large-scale system's modelling (Lee 1973), a failure of technocratic planning (Cardullo and Kitchin 2019), or cultural barriers within the planning profession (Geertman 2017), others identify a missing user's perspective during tool development (Pelzer et al. 2014). However, coming from the perspective of public administration research, there is little to no empirical insight how public servants presently use digital models and simulations in a city's multi-level governance system for integrated urban development. Given this research gap, scholars lack insight into how planning decisions are practically taken and how a city administration wants to use static and dynamic models in future processes.

Since recently, urban digital twins promise to bridge many of the aforementioned gaps (Batty 2024). Gathering attention from academics and policy makers alike, they come along with a renewed interest in dynamic models for 'What if?'-scenarios while at the same time integrating static representations of cities (Schubbe, Bodecker, and Moshrefzadeh 2023). As many European cities are in the process of implementing urban digital twins for more sustainable and resilient planning (Therias and Rafiee 2023), it seems especially important to investigate which kind of digital models and simulations practitioners require for future integrated urban development practices. Ideally, this could be one step forward to better integrate academic approaches with practical needs and strengthen the science-policy interface.

3. Methods

Given the different focus areas of the two research questions, we decided to conduct a cross-sectional survey of the city administration in Hamburg, Germany. Surpassing two million inhabitants in the upcoming decade, Hamburg is Germany's second largest city and is committed to a long-standing and regularly updated digital strategy (Freie und Hansestadt Hamburg 2025). Legally, it is both a municipality and one of Germany's sixteen states, granting it substantial room for manoeuvre for its planning and a multi-level governance system to practice integrated urban development. Within Germany's largest state-funded smart city project 'Connected Urban Twins', Hamburg is the leading city to develop and promote standards for urban digital twins, making it an exemplary city to study the current and future use of digital models and simulations for integrated urban development.

We designed the survey with two consecutive and methodologically different data collection phases (Creswell and Creswell 2018). In phase one, we created an online questionnaire to uncover explicit knowledge of which (simulation) models are used for which spatially relevant decision making processes. In phase two, we developed an interactive and collaborative web application for participants to leave comments, ideas and exchange with others to gather largely tacit knowledge which models and simulations are wanted for future urban development processes.

We connected both processes in an innovative, 'digilogue' survey design by sending out physical sensitizing packages with an individualized QR-Code to recipients. Sensitizing packages – ideally striking a balance between playfulness and professionalism – are design tools to encourage participants to deeply engage with a topic and spontaneously note ideas and comments (Visser et al. 2005). Each sensitizing package contained the building blocks of a miniature LEGO model of a generic urban context and a brochure with information about the study, the construction manual, and a QR-Code/link to the digital part of the survey (see Figure 1).

Since the notion of urban digital twins was not yet widely adopted at the time of the study, we designed its digital part to resemble a hypothetical and playful 'digital twin' of the physical LEGO model. Recipients, scanning the individualized QR-Code or visiting the webpage with their recipient link, were greeted to the study and shown a four-step process: (1) Assemble LEGO model and scan QR-Code (with a check mark, indicating its completion), (2) Fill out the questionnaire, (3) Write contributions in the digital twin and (4) Forward the study.

3.1. Data collection

For the first data collection phase, the questionnaire was structured into three sections. First, personal information of the survey participant was gathered, addressing their professional background, job title, main area of work and further information. Second, the status quo of their usage of digital models and simulations was inquired by openly asking which digital models and simulations they use in their occupation for which purpose(s).

Figure 1. A sensitizing package containing building blocks of a miniature LEGO city, a brochure and information how to participate in the survey.

Third and optionally, contact information for future outreach was collected. For a full overview of all survey questions, see the supplementary material.

For the second data collection phase, survey recipients were prompted to explore the 'digital twin' of the physical model (see Figure 2). The 'digital twin' was developed as reactive web application using three.js, React and a postgres database for data storage. The open-source code can be accessed here: https://github.com/citysciencelab/cut-modelling-simulation-survey. By selecting various buildings and urban infrastructures, recipients could see fictional descriptions, real-time sensor data, public participation contributions and related data sets of the specific object. Clicking a 'view' button, they could switch between an interactive 3D view, a birds-eye 2D view and a pedestrian perspective.

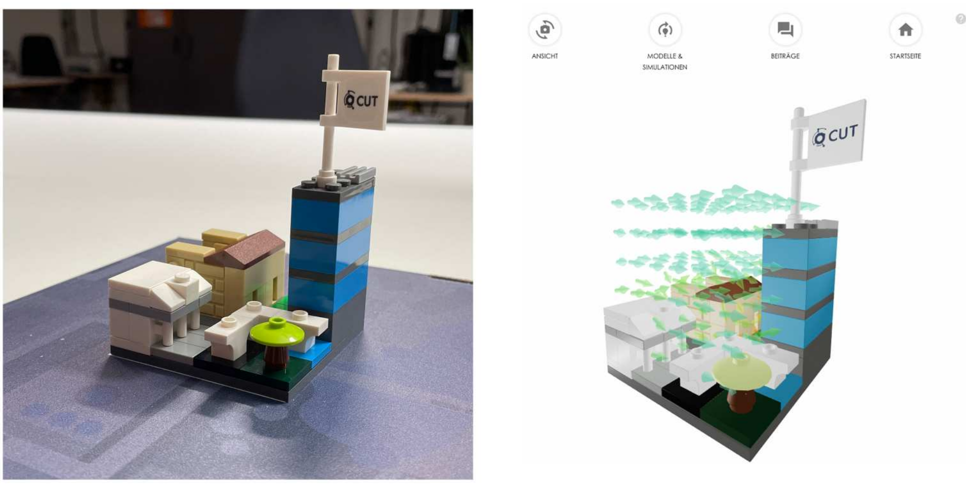

Figure 2. The assembled, physical LEGO model of an urban context and its 'digital twin' showing a wind-simulation.

Under a specific models & simulations section, participants could explore four different kinds of simulations: an air quality simulation, a shadow simulation, a wind simulation, and a heavy rainfall / flooding simulation. Other potential simulations, such as noise, heat islands, ecological niches, accessibility or mobility simulations were shown in greyed out to indicate that they could be possible but are not functional yet. For each simulation, recipients could adjust a parameter (daytime for the air quality and shadow simulation, wind direction for the wind simulation, amount of precipitation for the flooding simulation) and the visualization would update accordingly. They could also directly leave a comment and select an accompanying tag (either 'General', 'Request', 'Idea' or 'Question'). The main mode of data collection was the 'Contribution' section where recipients were prompted to answer the question 'Which (simulation) models would you like to use in the future? For what purpose?' after finishing exploring the fictional digital twin. Recipients could not only comment on their own wants but could also see other recipients' responses and reply to them either by text or by clicking on one of three emojis indicating a thumbs up, a light bulb or a thinking face emoji. Participants could choose to comment anonymously or in the name of their organizational entity. Using this interactive way of data collection, participants were encouraged to not only explore the concept of a digital twin individually but also engage in discussions with other public servants across departments and institutional boundaries. We decided for this way of data collection to encourage participants to 'think, reflect, wonder and explore aspects of their personal context in their own time and environment' (Visser et al. 2005, 123) while at the same time providing something tangible and playful to better grasp the concept of an urban digital twin. Additionally, it was important for us to also take up on the multi-layer governance aspects of integrated urban development by providing an enclosed digital space to exchange between departments and institutions.

3.2. Sampling strategy

The City of Hamburg, including the core administration and downstream state agencies and other statutory bodies, employs more than 70.000 individuals (Freie und Hansestadt Hamburg 2022). Screening organizational charts of all state-level ministries and seven districts, we selected a total of 86 different organizational units of the City of Hamburg to receive a sensitizing package. The selection was based on three selection criteria: First, a connection to spatial decision making could be inferred from the official description of the organizational unit. Second, a balanced sample of each of the core administration's bodies is ensured so that at least one organizational unit of every top-level governance body receives a sensitizing package. Third, a balanced sample of multiple levels of governance is ensured, including also the city's district and state agencies into the sample. The organizational chart of Hamburg's core administration, including all survey recipients on their governance level, is shown in Figure 3. For a detailed overview of survey recipients, see the supplementary material. The overall sample was further validated and refined with civil servants from the Office of IT and Digitization within the Senate Chancellery, the digitization department of the Ministry for Urban Development and Housing, as well as the State Agency for Geoinformation and Surveying. Survey recipients were also asked to forward the sensitizing package to other colleagues from their department.

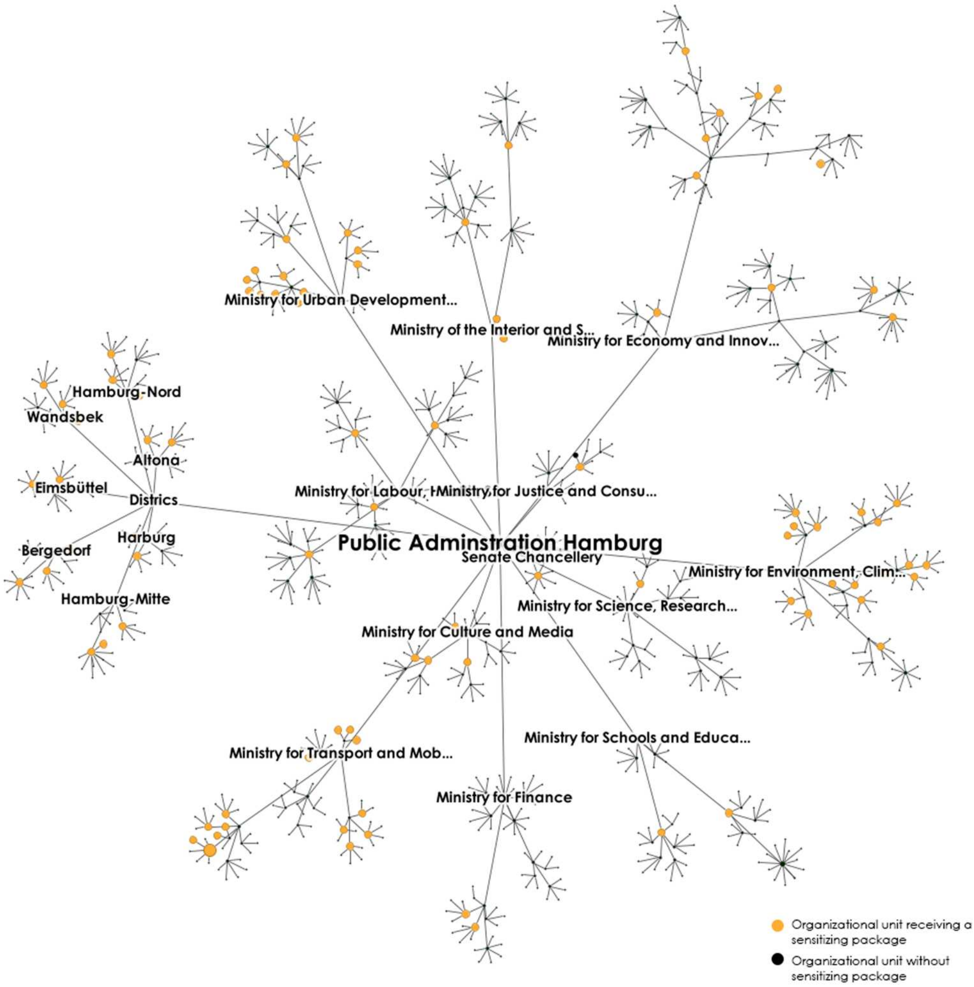

Figure 3. Survey recipients were selected across multiple levels of Hamburg's public administration.

3.3. Survey conduction and data processing

In October 2022, we sent out one sensitizing package to each of the selected entities via the city's interoffice mail together with a cover letter of Hamburg's Senate Chancellery. After 1.5 months of data collection, we reminded participants who had not yet replied. We finished the data collection before the winter holidays in late December 2022.

We consolidated the raw data by manually harmonizing the mentioned digital models and simulations and by inductively coding the responses of both survey parts into suitable categories. For the analysis of the status quo, we inferred if a model is a static or dynamic representation based on the model's description, name and purpose. For the contributions in the 'digital twin', we inferred different types of models requested based on the description provided. Whenever a single contribution mentioned multiple simulations, we added them individually to the induced categories.

4. Results

Of the 86 sensitizing packages sent out, 38 participants completed the survey (44.1% response rate). These respondents belonged to a total of 28 unique organizational units within seven state-level ministries and four districts of the City of Hamburg. The Ministry for Transport and Mobility Transition including its state agencies was the most responsive institution, followed by the Ministry for Urban Development and Housing and the different districts' responses. As shown in Table 1, most respondents saw a relation of their work to technical urban systems, followed by social systems and lastly ecological systems. A total of four respondents reported that their work is related to other systems, such as the geological underground or general data provision. Areas of work include land use planning, public participation, heritage protection, social planning, modelling of the underground, noise protection, transport planning, archival and historical work, port planning, planning of the hydrogen network, integrated neighbourhood development, planning of traffic infrastructure, building information modelling, 3D modelling, management of urban infrastructure, climate protection, and the creation of urban development concepts. Multiple respondents also mentioned the creation of domain-specific reports for within the administration as one of their core tasks, which entails the professional assessment of a planning project from their specific perspective. In terms of their position, 36.8% occupied a management position while the remaining 63.2% occupied non-managerial positions.

Respondents vary significantly in their amount of work experience. As shown in Figure 4, some participants just started to work in the administration while others are senior staff with more than 30 years of work experience. The average work experience of a survey respondent was around 7.5 years. Asked for their relation to the development of urban space, many recipients state that they take on an integrated perspective of weighing different spatial demands and finding compromises between sectoral interests. Others take on a more specific role, such as improving the sense of security for gender equity purposes in both physical and social space or promoting sports facilities in specific neighbourhoods. Various aspects of transportation planning were also reported,

Table 1. A total of 38 responses were collected across eight different municipal bodies. Note: Respondents mostly attribute their work to technical urban systems and social urban systems.

		Respondents working on			
Ministries & Districts	n=	Social systems	Ecological systems	Technical systems	Other systems
Senate Chancellery	1	1	0	0	1
Ministry for Culture and Media	3	3	0	3	0
Ministry for Urban Development and Housing (including the State Agency of Geoinformation and Surveying)	8	5	2	3	2
Ministry for Environment, Climate, Energy and Agriculture	4	0	3	3	1
Ministry for Transport and Mobility Transition (including the State Agency for Roads, Bridges and Waterways and the State Transport Authority)	10	4	5	9	0
Ministry for Economy and Innovation	2	2	0	2	0
Ministry for Science, Research, Equality and Districts	2	2	0	0	0
Districts (Bergedorf, Hamburg-Nord, Eimsbüttel, Wandsbek)	8	8	5	7	0
Total	**38**	**25**	**15**	**28**	**4**

Figure 4. The work experience of survey respondents varies between young professionals and senior staff with more than 30 years of experience.

such as working on a car-free inner city, bike lanes, blue infrastructure, or the planning of bus stops. Overall, the respondent sample exhibits a wide range of domain-specific knowledge, different governance levels, and different approaches to the development and planning of urban space, making it a comprehensive collection of public servants who are involved in integrated urban development and decision-making.

4.1. Status quo

The status quo of the reported usage of digital models and simulations differs greatly on the sectoral focus of the different respondent's institution. Figure 5 shows an overview of

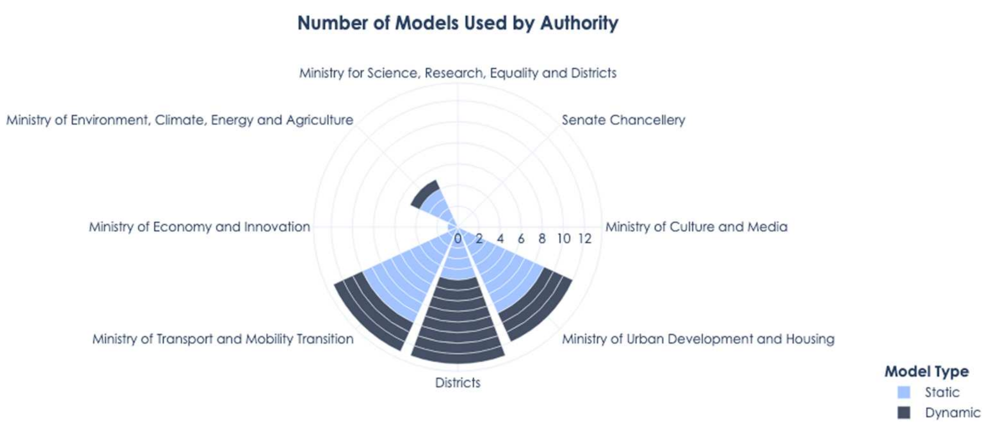

Figure 5. Different ministries and their departments vary greatly in their usage of digital models and simulations. While some report on using multiple different models, others mention none or very few.

both the number and the type of models used by the various respondents. The Ministry for Transportation and Mobility Transition, as well as the districts and the Ministry for Urban Development and Housing spearhead the usage of digital (simulation) models. The Ministry for Environment, Climate, Energy and Agriculture also reports on using mainly static models for their decision-making processes. Aside from the Ministry of Economy and Innovation, which is responsible for the planning and management of Hamburg's port, other respondents did not name any (simulation) model that they use for their decision-making processes. Broadly, institutions with a higher number of responses also report more models.

Categorizing the models into dynamic and static models based on the description provided by respondents, we find that around two thirds (65.9%) are static models and the remaining third (34.1%) are dynamic models. However, as a more detailed analysis of the models will show, categorizing the models into static and dynamic is sometimes ambiguous. The most common static models are the 'FHH Atlas' and the 3D city model (see Figure 6). Technically, the former is the city's own web-based GIS system where every civil servant has access to much of the city's open and internal data. It depicts the city largely as-is, and users have the possibility to activate multiple data layers on top of different base maps. Datasets range from environmental topics to data about the city's population, urban infrastructure, ecosystems, aerial imagery, health, mobility, energy, housing data, and many more. As different data owners update their datasets at different intervals, all datasets have a different timeliness. Some are real-time data of traffic counts or air quality measurements, and others are year-old data about species populating various biotopes. However, given the extensive list of data sets available, the FHH Atlas technically also displays data based on dynamic models, such as the modelled real-time flow conditions of the river Elbe. The description of respondents nonetheless indicates that they use the data portal as a static model of the city, displaying a snapshot of its current state. The 3D city model, the model which is mentioned the

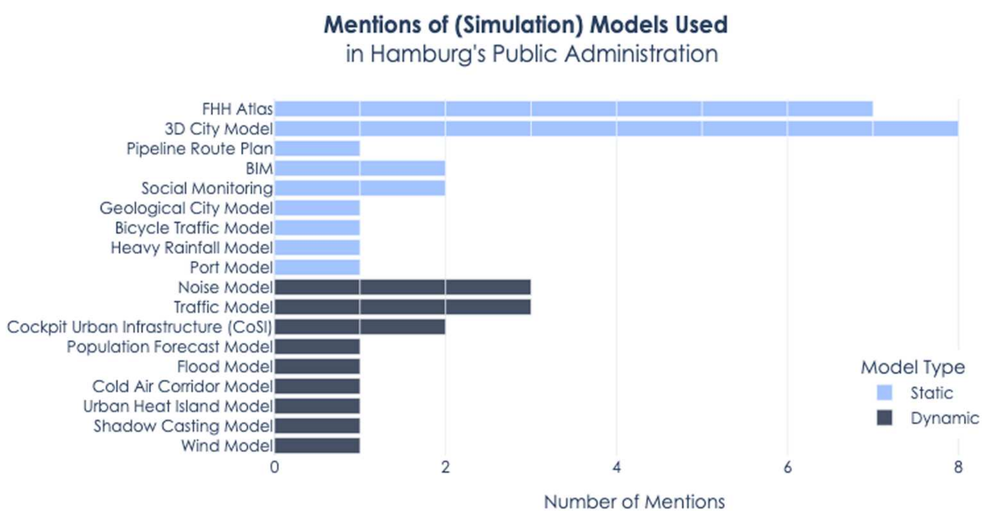

Figure 6. The most common static models used by Hamburg's authorities are the city's own datasets within the 'FHH Atlas' and the 3D city model, while the most common dynamic models concern noise, traffic and the expert planning system CoSI.

most frequent across all responses, is also accessible in a dedicated section of the FHH Atlas, showing a textured LoD3 model of the whole city with the possibility to display information about specific buildings. Other static models of the city include specific building information models (BIM), the social monitoring of the city which is based on a set of sociodemographic indicators, the underground pipe route and the geological model, the city's realtime bicycle count system, a heavy rainfall map and an AR model of the port's digitalization projects. With the exception of BIM and the AR port model, all other models are technically also domain-specific datasets which appear in the city's FHH Atlas. The heavy rainfall map on the other hand is an exemplary instance of a static model which is the result of a dynamic hydrological model – however where and how this dynamic model was used remains unclear.

For other dynamic models, noise models and traffic models were each mentioned three times by different respondents. As respondents describe, for instance, the 'calculation of the noise situation based on the city's 3D model' or the 'evaluation of traffic space allocation for the goal achievement', we inferred that the model in question is of dynamic nature. The Cockpit for Urban Infrastructure (CoSI), an expert planning system built on top of the city's FHH Atlas (Degkwitz, Schulz, and Noennig 2020), was mentioned twice. CoSI allows users to manually alter specific datasets and perform specific analyses – such as accessibility analysis and supply analysis of urban infrastructure – on the simulated data. Other dynamic models include shadow casting models, wind models, population forecasts, and environmental impact models (cold air corridors, urban heat islands, flooding models). One respondent explicitly mentioned that 'models are used to simulate traffic impacts, as well as shade and wind conditions of planned construction projects. I only use the models indirectly, but the modelling is incorporated into expert reports that are commissioned through my work'. This indicates that while some dynamic models are used by public servants themselves, others procure specific analyses and only receive the (static) results of the analysis.

The majority of digital models are used in the planning and coordination process. While most static models serve as a data basis across the board, dynamic models are largely used in the mobility and environmental sectors to provide a technical assessment of specific planning variants. Concerning social aspects of the city, an ongoing and yearly monitoring comprised of different sociodemographic indicators gives public servants data-based insights into social dynamics. Here, the model is not part of a technical assessment within an integrated planning process, but can be considered a starting point of tailored planning processes to (de)accelerate social dynamics in specific neighbourhoods. Similarly, the population forecast model is used as an input to provide sufficient housing. Another purpose of the models in use is public participation, where specific datasets are visualized to collect the public's feedback on planning variants.

4.2. Models and simulations for a future urban digital twin

A total of 33 textual responses and 15 reactions were collected in the 'digital twin' of the physical LEGO model. Out of these, 45.5% selected the category 'Request', 33.3% the category 'General' and the remaining 21.2% the category 'Idea'. After manually clustering the responses into different categories, most of the models mentioned are dynamic, ranging from environmental impact assessment models, urban development models, mobility models, energy supply models, feedback models and social infrastructure models (see Figure 7). Specifically for environmental assessment models, respondents mention wind simulations, precipitation simulations that take into account soil conditions, sensitive infrastructure and both duration and magnitude of rainfall, shadow simulations with a simple adjustment of building volumes, air quality simulations, and climate simulations and their impact on the city's port. For urban development simulations, multiple respondents lay a focus on socio-demographic developments by requesting a simulation of future changes of social infrastructure, as well as simulating the sociodemographic constitution of a new neighbourhood at the first move-in dependent on the neighbourhood's place, surroundings, price, and facilities available. Others wish to simulate the housing market changes in specific neighbourhoods depending on the aging of its population over time, and the port development given climate adaptation measures. One respondent also mentioned simulations of less car-centric cities with a focus on parking lots turning into green spaces. For mobility simulations,

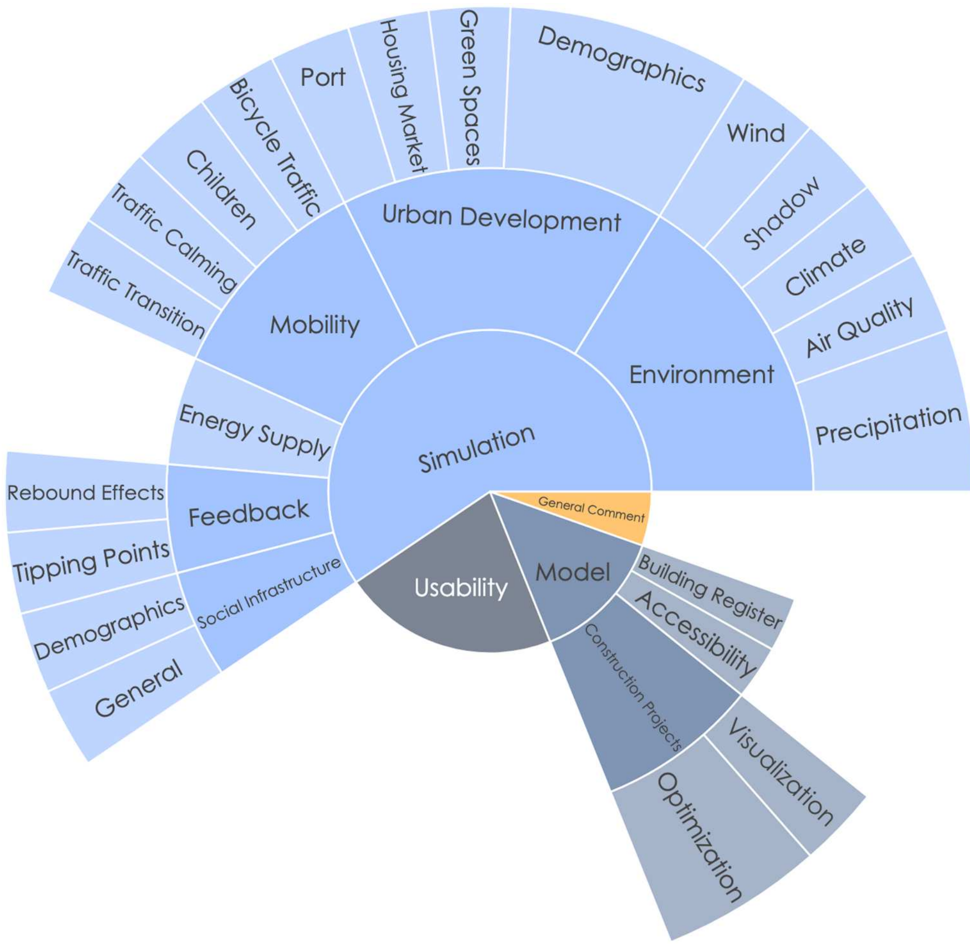

Figure 7. Participants mention a range of digital models and simulations that they would like to use in the future. They are mostly dynamic and cover a wide range of purposes, such as environmental impact assessment, urban development, mobility, energy supply, feedbacks and social infrastructure.

respondents wish to simulate the effects of traffic calming measures in certain streets and areas, particular aspects of mobility models such as children's mobility to kindergartens and schools, simulating an optimized bicycle traffic and simulating cities with less motorized private transport. Aside from these broad categories, respondents mention the simulation of future energy supply and storage within the city's districts and – on a more general notion – the integration of various models to simulate rebound effects and tipping points, such as capacity limits for certain intersections and streets. Specifically for social infrastructure, respondents wish to simulate future changes of social infrastructure and a fine-grained forecast of sociodemographic data of the future.

For static models, respondents mention a building registry with information about the age, number of floors, ownership structure, use, and, if applicable, the number of apartments of every building. Specific construction projects should be able to be visualized for better public participation processes and, in one case, a contribution mentions the specific 3D visualization of a planned project in a specific district and its climate impacts. Additionally, respondents request an accessibility model for facilities and mobility services and a model which optimizes the placement of buildings in an urban context.

Lastly, some respondents commented on the usability of the LEGO 'digital twin', suggesting improvements or highlighting certain features that they like. In one instance, a respondent remarked a more general aspect: 'Despite all the possibilities, no simulation is as good as reality, and cities must also take risks, tolerate mistakes, and forgive them. Good things can only be seen when bad things also exist. This is what characterizes the identity of each city, and it cannot be simulated. We should understand cities as living beings', to which another survey participant directly responded 'Isn't it also about avoiding mistakes

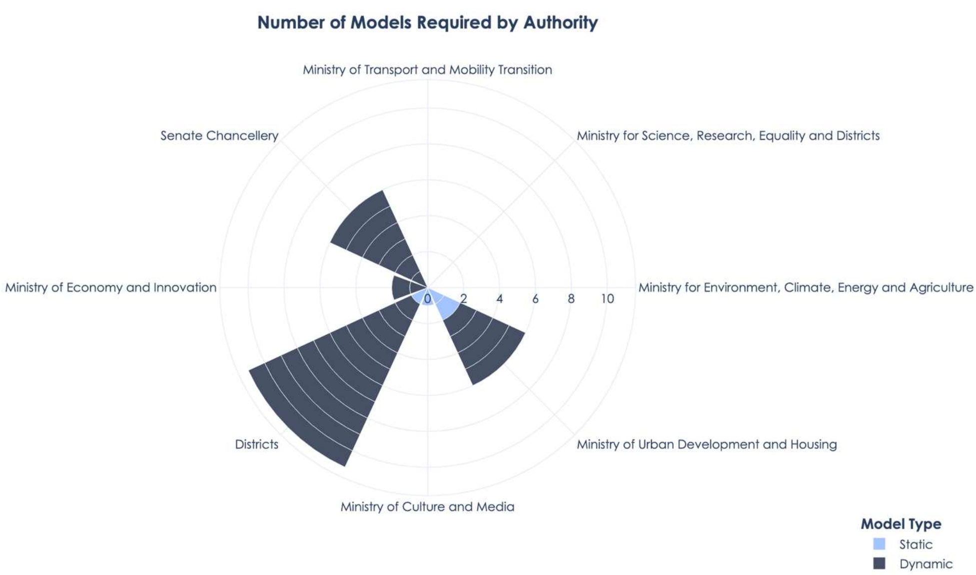

Figure 8. The requirements for future models and simulations in an urban digital twin differ across Hamburg's public administration. While there are substantial needs within Hamburg's districts and the senate chancellery, other ministries such as the Ministry for Transport and Mobility Transition of the Ministry for Environment, Climate, Energy and Agriculture did not contribute.

through simulations? Of course, urban spaces/neighbourhoods are highly complex systems, but by simulating such emerging living environments […], one can try to avoid known mistakes from the past (e.g. the formation of 'ghettos' through a combination of building density, social mix, design of public spaces and infrastructure, etc.)'. Interestingly, this general discussion remained the only instance of a direct response to another participant's contribution. However, six additional respondents made use of the thumbs-up emoji, signalling approval of a total of 15 other contributions without contributing themselves.

As shown in Figure 8, the authorities who contributed textually to the second part of the survey differ substantially from the first part. Organizational units attributed to ministries such as the Ministry for Transport and Mobility Transition or the Ministry for Environment, Climate, Energy and Agriculture who report on using multiple models in the status quo (see Figure 5), do not mention any additional digital model or simulation that they would like to use in the future. However, Hamburg's districts, as well as the Ministry of Urban Development and Housing and the Senate Chancellery engage frequently, showing indicators of ongoing digitization efforts. Contrary to the status quo, the vast majority of the models mentioned are of dynamic nature.

5. Discussion

5.1. From static models to dynamic simulations

Although exploratory in nature, the findings of this cross-sectional survey of the City of Hamburg's public administration can be interpreted as evidence for an ongoing paradigm shift in the administration's processes and practices of integrated urban development. While currently many of the models in use are static (i.e. spatial data sets within the city's own geoportal), the majority of requested models are of dynamic nature to simulate a range of urban development processes. At the same time, some of the city's authorities who already frequently use both static and dynamic models did not mention any future models, suggesting that the transition towards using data and simulation models for specific tasks is highly domain-dependent. For instance, the Ministry for Transport and Mobility Transition and its downstream state agencies already leverage several transportation models and do not state any models that they would like to use in the future.

The findings also hint towards potential synergies between different organizational units. Some of the models required by e.g. the districts are mentioned to be in use by other bodies of the administration. This gap could be explained by either lacking coordination between the city's departments or by different conceptualizations of what 'using a model' means in various settings. For the latter point, there is some evidence that specific dynamic models currently in use are not deployed within the administration itself but are rather repeatedly procured for project-specific expert reports by engineering companies or consulting firms. Decision making then happens based on the resulting static data layers that are delivered to public servants. This implies that in some cases, there is no competence in setting up and running specific simulations within the administration.

Many simulations wanted for a future urban digital twin concern topics of integrating different planning domains – such as the effects of mobility transition on public space, the effects of sociodemographic changes on the housing market, or the effects of climate change / adaptation on the port's development. From an organizational perspective, this would imply a departure from currently used domain-specific models tied to administrative responsibilities and competences towards new forms of technologically supported collaboration processes.

5.2. Towards a public digital twin infrastructure

For urban digital twins to turn into practically applied planning support systems that bring together academic modelling endeavours with administrative processes, the findings suggest that there are multiple gaps to bridge – both sociologically and technologically. As a prerequisite, the purpose of a given model must match with the competence of a given organizational unit in the administration. For instance, noise simulations are frequently used by different departments tasked with either designing the city-wide road infrastructure, evaluating environmental impacts or ones responsible for a specific district's infrastructure. Considering advanced land-use interaction models on the other hand, it seems that in the case of Hamburg, there is simply no administrative counterpart tasked with evaluating such changes in an integrated manner – land use and transportation are subjects of two different ministries. In case a model's purpose and an administrative unit's task align, the usage depends on the specific organization's culture and capacity for data analysis or running simulations. While in some instances the administration itself develops, deploys and uses models, in other cases external knowledge is bought in via expert reports and consultancy services. The science-policy interface is supposedly easier to establish and maintain when administrative units have the capacity and resources to transfer a growing number of urban models and simulations into their decision-making processes sovereignly. If a private third party is involved in providing a specific analysis for the city's decision making, a direct science-policy interface is much harder to form: Models and simulations have to be commercialized, integrated into a company's software stack and analysis methods, and then mentioned in calls for tenders and the downstream reports. Hence, for the change from static to dynamic models to happen as indicated in the survey results, both new public digital infrastructure and specific governance processes need to be developed and implemented to form an urban digital twin modelling ecosystem. Leveraging the private sector's competences to develop such infrastructure as open-source software would path the way to reproducible and transparent decision making processes and avoid costly, timely, and repeated procurements of expert reports. Examples from Hamburg already show that such an approach is not only feasible, but can lead to inter-municipal cooperation in developing their own tools instead of procuring off-the-shelf software licences (Tegtmeyer et al. 2022).

Furthermore, digital public infrastructure for modelling and simulation in urban digital twins could help to avoid a further entrenchment of sectoral solutions and lacking coordination between organizational units. Next to already established urban data platforms and emerging data spaces, a city-wide platform could become a key infrastructure to share dynamic models and algorithms between stakeholders. Existing infrastructure, such as the city's own geoportal could be extended to also integrate dynamic simulations. Lastly, the co-design of simulation models by different stakeholders could also foster new modes of collaboration within the digital city (Weber and Ziemer

2022). In this way, departments across governance levels could collaborate on different planning variants, scenarios, and their potential impacts.

5.3. Urban simulacra

The results also indicate that clearly defined theoretical concepts become blurry in the wake of increasingly digital, practical workflows. Multiple questions arise from the survey responses regarding the distinction of widely accepted definitions of static and dynamic models, simulations, and tools. For instance, if a static model is a formal representation of a natural system at one point in time, is the data layer of the simulated realtime flow conditions of the city's river still a static model? Or to put it more general: Are formal representations produced by other formal representations still considered representations of the original? Is the manual editing of a dataset and the subsequent accessibility analysis in a web GIS a simulation? If so, which parts of the web GIS constitute the dynamic model and which parts the interface? Are they even separable? Refining a clear nomenclature based on practical application and theoretical considerations would surely not only benefit the transfer from academic modelling to decision making, but also the exchange between different academic fields of planning support systems, modelling and simulation, GIS, city science, human–computer interaction, design research, urban digital twins, and many more.

Comparing such theoretical definitions of a model and a simulation with their practical usage, there are interesting parallels to Baudrillard's simulation theory and different orders of simulacra (Baudrillard 1999). Static models – e.g. data layers of urban infrastructure, sociodemographic data, etc. – used to be first-order simulacra of a given referent but increasingly become second or third-order simulacra: Representations of representations of representations of the 'real-world system'. If the trend towards integrated, dynamic simulations manifests, integrated urban development risks becoming increasingly hyperreal (Baudrillard 1999). Building on the arguments of Batty (2019) who theoretically discusses the place of urban digital twins in the map-territory relation and concludes that 'a (the) map is the territory', a hyperreal twin implies that 'the map […] precedes the territory' (Baudrillard 1999, 381). In its full extent, the city would become 'digilogue' – preceded by digital simulacra while at the same time shaped by analogue events. Hyperreal planning in this sense is a shift away from the classic distinction between representation and reality and towards outsourcing city making to algorithms. Ideally, this would not happen coincidentally, but with co-evolving ethical guidelines, governance structures and accountability mechanisms.

Although this survey provides initial evidence for such developments and the emerging AI urbanism could greatly accelerate them (Cugurullo et al. 2023), it is too soon to state conclusive remarks. Considering critiques and cautionary remarks of planning scholars (Hersperger et al. 2022; Potts 2020), diverse representations of the same system (Batty 2021) should be constitutive of increasingly mediated planning with higher-order simulacra in urban digital twins. Potentially, new signifiers would have to be developed to reflect this change: Like scales and north arrows that signify the relation between map and territory, new symbols of reference between the twin and the 'real' world could indicate the twin's agency, uncertainties, high-level assumptions and degrees of abstraction. For instance, a 'provenance braid' could depict various datasets, simulations and algorithms that are weaved at different stages with another to arrive at the current representation.

5.4. Engagement through sensitizing participants

Methodologically, this survey combines a questionnaire with an interactive online tool for participants to explore, note ideas and comments, and engage with the concept of a digital twin. Combined with sensitizing packages, we found that the survey not only yielded higher-than-usual response rates but also served a secondary purpose of being a door opener for contacts to various city departments. In the months and years after the survey, we found the LEGO model in the backdrop of online meetings with various public servants. While interviews could have likely enabled a more in-depth exploration of the status quo in some governmental sectors (see e.g. Kitchin et al. 2025), the interest to also inquire potential future applications of models and simulations and a more comprehensive sample across different smart city domains led to the decision to work with design research methodologies. Additionally, sensitizing participants also sparked an in-depth debate between different respondents about the nature of simulations, experimentation, and urban development.

5.5. Limitations

Multiple limitations come along with the study design and methodology. In terms of the survey sample, there are numerous other city-owned, but privately organized institutions which were not included in the survey sample but influence integrated urban development processes. Companies like the Hamburg Port Authority, the municipal housing corporation SAGA, the public transport provider Hochbahn and many more likely use multiple models in their decision making. These corporations can be seen not as primarily tasked with integrated urban development but largely implement the goals of higher-level institutions. Still, this survey has no intention of being statistically representative of the whole administration or exhaustive in its findings. Additionally, the findings presented in this paper are inevitably tied to Hamburg's public administration and its local settings. While other (German) cities might differ significantly in both their governance structure and their practice of integrated urban development, we argue that Hamburg is an exemplary case to study in multiple ways. First, it exhibits governance structures of both a municipality and a state. Second, several smart city rankings show that it is leading in both implementing urban digital twin applications and setting standards for all German municipalities (Schubbe, Bodecker, and Moshrefzadeh 2023). Hence, other cities are likely to resemble or follow best practices of the City of Hamburg in the future. Third, Hamburg actively invests in creating and maintaining software communities together with other cities and municipalities so that future digital public infrastructure can be transferred and co-developed with other cities.

6. Conclusion

Digital models and simulations play an increasingly important role in integrated urban development. While many of such models are being created in academia for the purpose of better decision making, there is little evidence of how a city administration currently uses them and plans to use them in the future. By providing initial evidence from the city administration of Hamburg, Germany, we find that the current usage largely depends on the sector and on static representations of urban systems. For a future urban digital twin development, many departments mention dynamic, integrated simulations of different urban systems. Aside from potential synergies between administrative units, we argue for new digital public infrastructure that strengthens the science-policy interface and new collaborative processes in urban planning, while at the same time reflecting hyper-real tendencies of urban digital twin developments.

Research ethics

There was no ethics committee present at the university at the time of survey conduction. Nonetheless, the information security and data protection officer was involved from the beginning onwards and assisted to design the survey in line with all GDPR requirements. All participants agreed to the data protection notice and provided their informed consent before taking part in the survey. The data was stored on the university's servers with a specifically developed tool.

Usage of artificial intelligence

Generative AI tools, specifically ChatGPT v5, have been partially used for the sole purpose of language editing this article. This concerns the following sections: Abstract, Introduction, Background. The remainder of the article was created without the usage of generative AI.

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