Connected Urban Twins

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GUIDE TO MODEL LAND

A GUIDE TO ETHICAL QUESTIONS FOR MODELING AND SIMULATION IN URBAN DIGITAL TWINS

„There is a theory which states that if ever anyone discovers exactly what the Universe is for and why it is here, it will instantly disappear and be replaced by something even more bizarre and inexplicable. There is another theory which states that this has already happened.“

Douglas Adams, Author of „The Hitchhiker's Guide to the Galaxy“

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BACKGROUND

This "Guide to Model Land" was created as part of the transformative experimental research in the "Connected Urban Twins" project at the City Science Lab of the HafenCity University Hamburg. It is based on comprehensive theoretical and practical experiences in modeling, simulation, AI, and machine learning. "Connected Urban Twins" is one of the largest smart cities model projects funded by the Federal Ministry of Housing, Urban Development and Building. It aims to create common standards for urban digital twins in the cities of Hamburg, Munich and Leipzig and beyond.

This document provides initial impulses for the ethical handling of the development and application of simulation models in urban digital twins.

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EXECUTIVE SUMMARY

"What if?" scenarios in urban digital twins are based on mathematical models and simulations. Being simplified representations of a real system, such models allow us to digitally experiment with various alternatives and make better-informed decisions for real urban development problems. Each simulation places us in "Model Land": that abstract and boundless land of mathematical relationships and calculations. Numerous decisions must be made to enter, navigate and exit Model Land towards reality.

This "Guide to Model Land" is intended to be a practical guide to ethical issues concerning digital simulation models. It is divided into three sections: Entering Model Land, Navigating Model Land and Exiting Model Land. It was created based on extensive literature research and offers guidelines as well as references to further relevant literature. The following eleven guidelines were developed:

Entering Model Land: Creating Models

1. No model without the modeled: Involve represented stakeholders
2. Fit for purpose? Define and communicate the model's purpose
3. Document value judgments and assumptions
4. Is it useful? Verify and validate the model
5. An engine, not a camera: Understand models as co-creators of reality

Navigating Model Land: Simulating Models

6. Deal transparently with uncertainties
7. Multiple models instead of one: Using multi-modeling methods
8. Optimized scenarios for certain futures, robust scenarios for uncertain futures
9. Artificial Intelligence: Informed, transparent and responsible use of AI models

Exiting Model Land: Using Model Results

10. The quantitative exit: Publishing calculations and results
11. The qualitative exit: Describing and contextualizing results

The guidelines in this guide provide an overview of points discussed in the scientific literature. They do not claim to be complete or universally valid. Every modeling process inevitably depends on the system being modeled and can therefore vary greatly.

Many of the points mentioned relate to the modeling of social and human behavior, which raises additional ethical questions.

THE ETHICAL DIMENSION OF MODELS AND SIMULATIONS IN URBAN DIGITAL TWINS

Argentinian novelist Jorge Luis Borges describes in his short story "On the Exactitude in Science" the tale of a people of cartographers who aim to create the most exact maps of their kingdom. Eventually, after countless years of work, the maps' dimensions and level of detail take on the kingdom's size and cover everything else. The people fail themselves. Only a few ruins remain.

What does this story tell us? Abstraction is necessary for something to be useful in an application. If a map includes too many details, we can no longer use it for good navigation.

Model building is good abstraction for a specific purpose. A model is understood as a simplified representation of an "original"[1]. Models are application-specific and tailored to their creators' wishes: In the natural sciences, they describe empirically measurable phenomena, in engineering, they predict certain properties under changing conditions, and in the humanities, they help understanding complex human patterns. But models and modeling find broad application not only in the sciences; people also enjoy model cars, trains, ships, and planes or use navigation apps on their smartphones to navigate. Ultimately, everyone creates "mental models" of reality to understand, organize, and make use of the surrounding complexity[2].

[1] Stachowiak, H. (1980). Der Modellbegriff in der Erkenntnistheorie. Zeitschrift für allgemeine Wissenschaftstheorie, 11(1), 53–68. https://doi.org/10.1007/BF01801279

[2] Jones, N. A., Ross, H., Lynam, T., Perez, P., Leitch, A. (2011). Mental Models: An Interdisciplinary Synthesis of Theory and Methods. Ecology and Society, 16(1). https://www.jstor.org/stable/26268859

The english statistician George Box succinctly summarizes the implications of this abstraction:
"All models are wrong, but some are useful." This means that while models can be useful for specific tasks, a comprehensive "correctness" must be denied. For example, a model may reliably predict a car's braking maneuver but is unlikely to simultaneously consider paint wear due to environmental influences or the exact pollutant emissions during braking. Another model might be useful for understanding fundamental relationships but cannot reliably predict the future. The specific application and usefulness of the model are the criteria.

As soon as we simulate a model, we enter "Model Land," as Erica Thompson calls the world of mathematical models[3]. Increasing amounts of data are generated to give us insights into the real world. However, both the design of Model Land and the way back to the real world can quickly become challenging. How do we behave correctly? How and where should we develop "Model Land"? Whom do we grant access to? Whom not? How do we find the way back safely? And what happens when inscrutable entities called "Artificial Intelligence" suddenly emerge in "Model Land"?

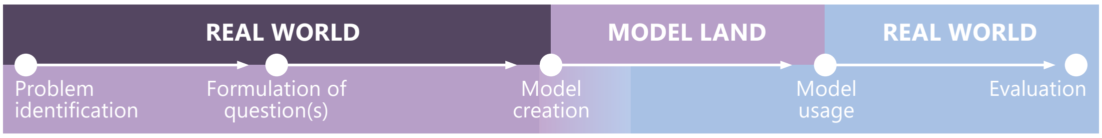
[3] Thompson, E. (2022) Escape from Model Land. How mathematical models can lead us astray and what we can do about it. ISBN-13: 9781529364873

Various ethical questions arise regarding the development, integration, and application of models and simulations in digital urban twins. Without presenting conclusive answers, this text addresses some of the emerging questions and offers initial ethical guidelines. It is based on extensive literature research referring to modeling and simulation, scientific ethics and artificial intelligence.

To stay in the metaphor of "Model Land" and the tradition of Borges' cartographers, the guidelines are structured into the sections "Entering Model Land," "Navigating Model Land," and "Exiting Model Land."

ENTERING MODEL LAND: CREATING MODELS

Before entering Model Land, the real system must be examined. The problem and purpose of the model must be described, a question must be formulated, and the entire modeling process must be organized. Numerous decisions based on different assumptions, values, and goals are made in this negotiation process. Several ethical principles are repeatedly discussed in the literature for this process.



1. No model without the modeled: Involve represented stakeholders

When specific groups of people are modeled, and human behavior matters, a model's biases and potentially discriminatory design can be counteracted by including a variety of perspectives in the process. New viewpoints can be gained and structural problems can be identified.

If part of the model represents social actors, the principle "No model without the modeled" should apply[4]. Co-modeling or participatory modeling methods for example can be used to achieve this.

[4] Tolk, A., Clemen, T., Gilbert, N., & Macal, C. M. (2022). How Can We Provide Better Simulation-Based Policy Support? Annual Modeling and Simulation Conference (ANNSIM), 188–198. https://doi.org/10.23919/ANNSIM55834.2022.9859512

FURTHER QUESTIONS

How can an appropriate and safe space for goal-oriented communication be created?
How is the process guided and moderated without having a directional influence on the participants' responses? What effects does the observation of social structures have on them, and can such discrepancies between reality and the model be reduced?

2. Fit for purpose? Define and communicate the model's purpose

Before starting the modeling process, the purpose should be clear to all involved parties: What is the objective? Which question should be answered? Which actions should be represented? For what can the model be used? For what not? As many people and institutions may be involved in the process, clear and documented agreements and structures are needed. The diagram below shows the different instances that can work together in the process. Since various stakeholders represent different interests, have different access to information and possibly pursue different objectives, it is necessary to find suitable and tailored solutions for each process.

3. Document value judgments and assumptions

Value judgments and assumptions are inevitably made during the modeling process. These start with deciding which aspects should be integrated into a model and which not, addressing the selection of actions in the model, and end with the question of which results the model permits. Societal preferences, zeitgeist, as well as individual values inevitably shape this process. Whenever value judgments and assumptions are made, they should be documented transparently so users are aware of their existence.

FURTHER QUESTIONS

What is fixed and what is changeable? Which laws or regularities may/should be changed in the digital model? What is under debate or what may be subject to debate when modeling 'what if' scenarios? Which behavioral theories are selected and for what reasons to implement complex human behavior in models? To what extent can theories formulated in the past be brought into the current context to shape the future?

4. Is it useful? Verify and validate the model

For a model to be used effectively for its intended purpose, it must be verified and validated as thoroughly as possible. Verification ensures no programming errors are present and that the algorithms within the model calculate the intended outcomes. While this may sound trivial, it requires significant resources and extensive testing to verify the correct units in practice.
The process of validation concerns the match of the model with the real system. There are various methods, such as historical validation or expert validation[5]. However, depending on the system represented, historical validation may provide deceptive security. Just because a model explains the past in hindsight does not necessarily mean it can reliably predict the future. To summarize, verification answers the question, "Did we build the model correctly?" while validation answers the question, "Did we build the right model?".

[5] Cook, D. A. (2005). How to Perform Credible Verification, Validation, and Accreditation for Modeling and Simulation. CrossTalk: The Journal of Defense Software Engineering, 2024.

5. An engine, not a camera: Understand models as co-creators of reality

Building models involves numerous decisions that determine the model's immediate boundaries. However, the consequences a model has beyond its boundaries on human decision-making are not calculable. According to the analogy "an engine, not a camera," a model is a co-creator of reality[6]. It reinforces or hinders actions and influences the scope of possibilities. An economic model, for example, cannot represent prices without automatically influencing price development. Therefore, numerous questions arise in the modeling process, which must be answered for each case, but there is no universally valid or "correct" answer. Depending on the perspective taken, the context in which the object of consideration is embedded, the parameters included, how the results are interpreted, etc., fundamentally different models can arise from the same initial question. In this process dynamic, decisions made should be critically reflected and documented. In complex systems like a city, nuances of changes can significantly impact the model's outcome ("butterfly effect").

[6] Thompson, E. (2022) Escape from Model Land. How mathematical models can lead us astray and what we can do about it. ISBN-13: 9781529364873

Problem identification

- How was the problem brought to attention?
- What data underlies the problem identification?
- What is the scale of the problem?
- Have similar problems already been modeled?
  What perspective do they take on the problem?
- Were crucial parameters overlooked in existing problem treatments?

Formulation of question(s)

- What is an appropriate framework for narrowing down the question?
- Are there multiple questions related to the same problem?
- Should these questions be modeled in a single model or in multiple models?
- Which areas are indirectly related to the problem?
- Are they important to consider?

Conceptualizing the process

- What is the purpose of the model?
- Who is involved?
- Which parameters are relevant? What uncertainties exist?
- Which parameters are intentionally omitted and why?
- How is data collected, stored, used, structured, visualized, and provided?
- Should the model be qualitative, semi-quantitative, or quantitative?
- What technological means are used? Is AI being employed?
- What theories underpin the modeling of social structures?

Model creation

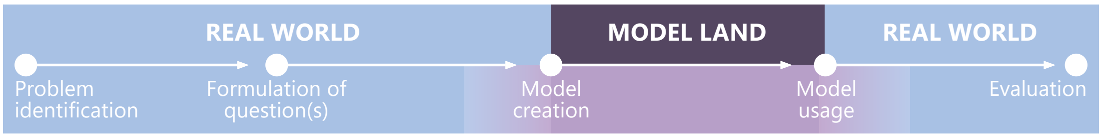
- How are social values, human behavior, and emotions translated into code?
- How are subjective and individual experiences meaningfully translated and incorporated?
- How relevant are they to a central/general problem?
- How flexible and reusable is the code?
- How is the model validated and verified?

The graphic above shows a small selection of a catalogue of questions that accompanies the entire modelling process and should always be developed further.

Models do not necessarily have to be an exact reflection of reality in order to be "good". They can tell their very own story in order to gain new insights, disseminate knowledge, show alternatives and understand reality in a certain way. They are not just accumulations of data, facts and calculations, but they are directly interwoven with ethical, social and political values.

NAVIGATING MODEL LAND: SIMULATING MODELS

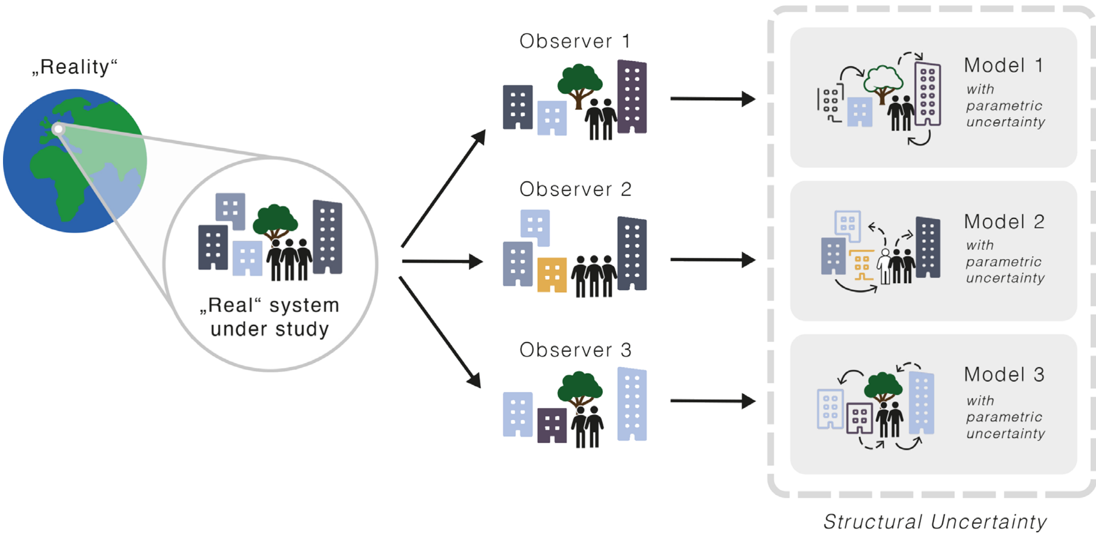
Once in Model Land, various questions arise regarding uncertainties along the way, simulation of models, and using artificial intelligence. These will be addressed in the following section.



6. Deal transparently with uncertainties

Depending on the system and model, various types of uncertainties arise. In most engineering models, the interaction of uncertain parameters can be well quantified. However, in complex systems, one quickly reaches a point where classical probability theory is only of limited help. Whether due to different actors' divergent understanding of the system's relationships or differing evaluations of the results, systems at such a level of uncertainty ("deep uncertainty") require a fundamentally different approach to dealing with uncertainty. Here, there are not only uncertain aspects or parameters of a model, but the model's structure and implementation are also characterized by uncertainties that can no longer be quantified. The diagram below schematically shows these uncertainties.

In any case, uncertainties should be dealt with transparency. Especially in systems with properties of "deep uncertainty," calculated scenarios in Model Land should be used as tools for exploring possible futures, not as predictions of a future that will occur with a specific probability. Simultaneously, the quality of the data used is crucial for a useful model and its uncertainties.



7. Multiple models instead of one: Using multi-modeling methods

In the case of uncertainties about the best representation of a real system, multi-modeling methods should be used.[7] The general idea is that multiple models of the same system contribute to a more comprehensive understanding. Simulating these models allows for assessing the extent to which the statements of a single model align with those of others. If there is high agreement, confidence in the models' statements grows. If model results diverge significantly, investigating the causes of this divergence can contribute to a better understanding of the system.

[7] Batty, M. (2021). Multiple models. Environment and Planning B: Urban Analytics and City Science, 48(8), 2129–2132. https://doi.org/10.1177/23998083211051139

[7] Page, S. E. (2018). The model thinker: What you need to know to make data work for you (First edition). Basic Books.

8. Optimized scenarios for certain futures, robust scenarios for uncertain futures

Depending on the model and the uncertainties involved, different objectives should underly scenario creation. When uncertainties in the model are low, optimization algorithms can be used to find the best solution to a problem. For example, noise in a courtyard can be minimized through the optimal arrangement of buildings.

However, sometimes calculating a single number of scenarios is insufficient. Although a "business as usual," a "best case," and a "worst case" scenario might frame the scope well, in many cases a wide range of possible futures can only be explored through the structured calculation and analysis of hundreds or thousands of scenarios. This is especially true when significant uncertainties and/or numerous assumptions have been incorporated into the models. Then, appropriate methods should be used to find robust scenarios that deliver acceptable results across a wide range of uncertain futures.[8]

[8] Walker, W. E., Marchau, V. A. W. J., & Kwakkel, J. H. (2013). Uncertainty in the Framework of Policy Analysis. In Public Policy Analysis: New Developments (S. 215–261). Springer Science+Business Media.

9. Artificial Intelligence: Informed, transparent and responsible use of AI models

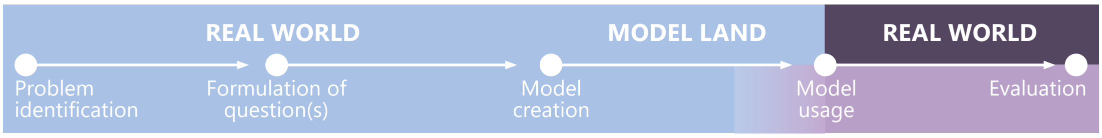
With the ever-increasing amounts of data and their processing, AI's use as an information processing aid becomes more prevalent due to its many potentials. Ultimately, AI is also a mathematical model that produces outputs given certain input parameters. However, oftentimes it is difficult to understand exactly how the results are achieved due to the models' inner workings ("black boxes"). With the establishment of guidelines, framework conditions and best practices, AI governance documents are intended to provide a responsible, ethical and socially framework for the use of artificial intelligence that is ethical and in line with social values. In this context, references can be made to the EU AI Act and research on AI governances.[9] One of the key points is the transparent information and education about the type of AI used in decision-making processes. Decisions made by people based on AI-generated data should always be openly communicated.

[9] Jobin, A., Ienca, M., Vayena, E. (2019). The global landscape of AI Ethics Guidelines. Nature Machine Intelligence (1). https://doi.org/10.1038/s42256-019-0088-2

Furthermore, the responsibility and liability for possible damages caused by AI use should be clarified. This clarification reduces the anonymity behind AI decisions and gives technical structures a more tangible connection to the real world.

EXITING MODEL LAND: USING MODEL RESULTS

To draw conclusions about the real world from simulation results, the obtained data must be interpreted and prepared as effectively as possible for the decision-making process.



10. The quantitative exit: Publishing calculations and results

Once validated results are available, they should be made available to a broad public so that replicability is possible. Especially when significant societal decisions are made based on a model, the model and experiments with it should be made available. This allows other experts to review the results and possibly contrast assessments.

11. The qualitative exit: Describing and contextualizing results

Simulation results often do not speak for themselves and can only be transferred to reality when contextualized. Often, people not involved in the creation process or without specific expertise in modeling and simulation cannot draw the correct conclusions from pure quantitative data. The exit from Model Land is then predominantly qualitative. The extensive knowledge gained through creating and experimenting with the model(s) must be prepared and documented transparently. The results are always embedded in a narrative that must be reflected upon and designed responsibly. If the most common way out of Model Land is qualitative and depends on experts, the qualitative exit also raises the question of trust in the model creators and their assumptions.

Particularly non-experts who make decisions based on the models' results must be extensively informed and sensitized about the model's purpose and limitations. When human behaviors in simulations are modeled, it should be noted that these cannot be modeled in all their nuances. An understandable explanation of the selection and assessment of parameters is essential and can help reflect on process decisions. Simultaneously, such an explanation can form the foundation for a constructive discourse at eye level.

FURTHER QUESTIONS

How precisely are the results presented in the end? Do they leave space for interpretation, or are they clearly formulated? How and by whom are the results translated for non-experts? To whom are they accessible, and in what kind of way? Was it done in the best interest of everyone?
To what extent is the model influenced by the factor of time? Does it represent a specific point in time, a time span, or possible future developments? Was this adequately indicated?
Is it feasible, through the chosen method of presentation, to reach people who previously had no relation to the topic? What bias is recognizable in the model? How was this addressed? To what extent can the model be optimized? What can be learned for future models?

FURTHER LITERATURE

Dennehy, D.; Griva, A.; Pouloudi, N.; Dwivedi, Y.; Pappas, I.; Mäntymäki, M. (2021). Responsible AI and Analytics for an Ethical and Inclusive Digitized Society. https://doi.org/10.1007/978-3- 030-85447-8_21

Derman, E., & Wilmott, P. (2009). The Financial Modelers' Manifesto. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.1324878

Greene, D.; Hoffmann, A.; Stark, L. (2019). Better, Nicer, Clearer, Fairer: A Critical Assessment of the Movement for Ethical Artificial Intelligence and Machine Learning. Proceedings of the 52nd Hawaii International Conference on System Sciences. URI: https://hdl.handle.net/10125/59651
ISBN: 978-0-9981331-2-6

Helbing, D.; Fanitabasi, F.; Giannotti, F.; Hänggli, R.; Hausladen, C.I.; van den Hoven, J.; Mahajan, S.; Pedreschi, D.; Pournaras, E. (2021). Ethics of Smart Cities: Towards Value-Sensitive Design and Co-Evolving City Life. Sustainability, 13, 11162. https://doi.org/10.3390/su132011162

Leclercq, E.; Rijshouwer, E. (2022). Enabling citizens' Right to the Smart City through the cocreation of digital platforms. Urban Transformations 4:2 https://doi.org/10.1186/s42854-022-00030-y

Mittelstadt, B; Allo, P.; Taddeo, M.; Wachter, S.; Floridi, L. (2016). The ethics of algorithms: Mapping the debate. Big Data & Society: 1–21 https://doi.org/10.1177/2053951716679679

Nallur, V. (2020). Landscape of Machine Implemented Ethics. Science and Engineering Ethics. 26:2381–2399 https://doi.org/10.1007/s11948-020-00236-y

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