Urban Modelling: Quantitative and Qualitative Approaches

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1. Research Context: Urban Complexity Research and the Role of Models in Understanding and Managing Urban Complexity

A large number of contributions have proposed complexity as *the* key characteristic of the city and have in various ways called for a transdisciplinary research programme organised around the integrating paradigm of 'complexity' (cf. especially Eckardt 2009; Albeverio *et al.* 2008; Batty 2009, 2013; Portugali 2011, 2012a, 2012b).

Portugali (2006) conveniently defines the complexity of the city thus: "a very large number of interacting parts, linked by a complex network of feedback and feedforward loops, within a system that is open to and, thus part of, its environment" (657; cf. also Portugali 2011, 232). Further characteristics of complexity frequently discussed include self-organisation, emergence, non-linearity, phase transitions, density, mobility (as one cause of change over time and as the occasion for increased interaction and mixing), ethnic and cultural multiplicity, heterogeneity and hybridity, violence, conflicts over the use of space, intersections of technology and virtual spaces with physical spaces, overlapping and intersecting spatial scales – from the local to the global – and their interdependencies, as well as complex interferences, interdependencies or intersections in the interaction between multiple players, intentions, or force fields. Together, these make urban systems prime examples of translocal networks of complex relationships, connections, and interdependencies subject to rapid change over time. Moreover, as already indicated in Portugali's working definition, the city is of course an open or dissipative rather than a closed system (in the technical sense): It exchanges goods, energy, information, people, money, etc. with its environment. All these characteristics, it seems, are more or less part and parcel also of urban simulation models in the more technically oriented disciplines concerned with urban modelling from a complex systems perspective. However, the 'softer', less easily quantified and modelled characteristics of urban complexity are no less central to the 'urban experience'. In this vein, in addition to the 'usual suspects' such as "hierarchy and emergence, non-linearity, asymmetry, number of relationships, number of parts", Mainzer (2007, 374) also lists the following features:

"values and beliefs, people, interests, notions and perceptions" (they appear in a visualisation, hence in no particular order). Additionally, while the notion of a system's 'history' – in the sense that previous developments have an impact on the present and future course of the system – is central to urban modelling (if only in the sense that past developments can be extrapolated for predictive purposes), one specific aspect of a city's history is of particular importance to an understanding of urban systems from the perspective of literary and cultural studies: This is the notion of the city as a palimpsest, a form of layered spatialized memory.

The Role of Models in Understanding and Managing Urban Complexity

Models can be regarded as a central tool in any attempt to understand and manage urban complexity. According to a general theory of models (cf. Stachowiak 1973, 131–133), all models share the characteristics of being (1) representational, (2) reductive and (3) pragmatic. Thus, a model may be defined as a simplified physical, digital or mental representation of a more complex outside entity to which it must be functionally or structurally similar in order to function as a model. Models are devised or chosen for a specific purpose and – depending on that purpose – will selectively focus on different characteristics, elements or connections of the system perceived as central to this purpose, while disregarding others. Thus, a map of a city with colour-coding in green, yellow or red to represent high, medium or low average incomes per district is a model of that city in that it (1) represents the city, (2) does so in a highly selective, simplified, abstracted and aggregate form, and (3) does so for specific purposes – possibly to support decisions about where to launch social cohesion programmes – while it would be largely useless for other objectives.

Compression and strategic 'reduction' of complexity are of course part and parcel of any modelling process, as Stachowiak's notion of "reduction" ["Verkürzung"] as central to any model already makes clear (132). The crucial task in the building and use of models, therefore, is to decide what can safely be left out or abstracted so as not to distort the overall picture. This will naturally depend on what the model is supposed to achieve – whether, for instance, to help understand all interdependencies within a system or whether to capture only those features of a system perceived as relevant to a specific investment decision. In both cases, the heuristic nature of the model is not to be ignored.

Moreover, mathematician and information theorist Bernd Mahr has argued that models should additionally be understood in their dual nature of always being both "models *of*" something and "models *for*" something:

> A model is always based on something *of* which it is a model, i.e. departing from which or referring to which it has been produced or chosen, its matrix. The purpose of building or choosing a model is its use. […] One of the typical uses of models is their use as a *means of designing* [*or creating*] something. [Here] models are samples, pre-formations or specifications. […] The notion of the model can therefore only be explained convincingly if it is acknowledged that a model is always both a *model of something* and a *model for something*. (2015, 331f.; italics original; our translation)

Adapting this notion, a model can be understood as being to varying degrees both the *descriptive* rendering of an entity *of* which it is a model and – at least implicitly – the *prescriptive* blueprint for the design or transformation of a future entity *for* which it is a model. Building on this understanding of models, the present chapter selectively discusses two fundamentally different types of models, quantitative models in Operations Research on the one hand, and verbal models in literary and in pragmatic texts as one specific type of qualitative model on the other hand.

2. Quantitative Models in Operations Research

2.1 Overview

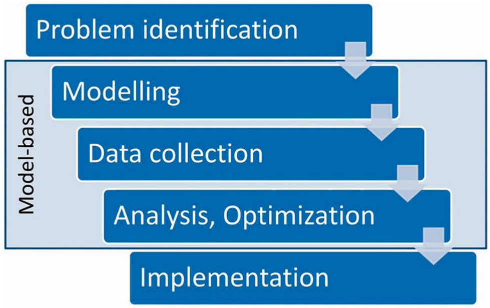
In operations research (OR), a model is a *task-driven, purposeful simplification and abstraction* of a perception of reality, shaped by physical, legal, and cognitive constraints. It is task-driven, because a model is built with a certain question or task in mind. Simplifications leave all the known and observed entities and their relations out that are not important for the task. Abstraction aggregates information that is important to become more general and, thus, gain relevance beyond a singular observation or use case. Both activities, simplification and abstraction, are done purposefully. However, they are done based on a perception of reality. This perception is already a model in itself, as it comes with a physical constraint. There are also constraints on what we are able to observe with our current tools and methods.

The *model type* is the language used to represent the outcome of the above-described process of model building. Its choice is clearly interrelated with the processes of simplification and abstraction, but choosing a model type is an important decision of its own that is largely driven by the model's purpose. The choice of the model type often precedes model building and actually determines already what can be easily captured in the model and what can not, usually because capturing a certain aspect would dramatically increase the model's size and complexity. For example, if we consider models of a car, a physical model made from Lego, a 2D drawing, and mathematical formulae clearly each have different advantages and disadvantages.

Models are central to Operations Research. In a way, they can be viewed as the interface between the discipline and the real world. The Analytics process depicted in Fig. 1 captures a standard approach to real-world problems. Starting with the identification of the problem, it is then formalized, i.e. a model is built. Scientists then work with this model, which often includes data collection to create instances, analysing the model and/or the instances (e.g., solving, simulating). Finally, the results are relayed back to the real world and implemented. Here, the need to change or refine the model may arise, starting a new cycle.

In the following, we discuss the three most important model families: *Forecasting models* seek to predict future states of the world. *Simulation models* are a subgroup of forecasting models that often capture stochastic influences and make predictions by playing through complex systems. Finally, *optimization models* provide decision support by determining the best alternative according to an objective function.

Fig. 1: Analytics Process

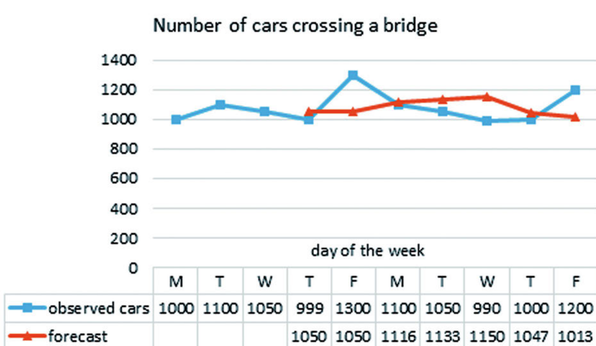


2.2 Forecasting Models

Forecasting models seek to *predict future events*. Usually, subjective (e.g., the Delphi method) and objective forecasts are distinguished. Operations research focuses on quantitative, objective forecasting models. A popular family of approaches uses past values from a *time series* to forecast future values.

As a simple example, we consider forecasting the number of cars crossing a bridge on a working day using the moving average method (see Fig. 2). In particular, the prediction for a day equals the average of the last three days (so-called MA[3]).

Fig. 2: Forecasting the number of cars crossing a bridge using the moving average method



Over the years, a plethora of forecasting models have been developed. In our example above, we may want to include the weekends, but account for the fact that traffic is usually reduced because no commuters are on the roads. Fitzsimmons et al. (2014) provide a tutorial on the most basic approaches, whereas more formal introductions include Henry et al. (2019) and Brockwell and Davis (2016).

2.3 Causal Models

Causal models focus on the relationships between exogenous and endogenous variables. They seek to *describe the causal mechanisms of a system* and often involve a strong simplification. Causal models allow some questions to be answered from existing observational data without the need for an interventional study such as a randomized controlled trial. They can also help with the question of external validity (whether results from one study apply to unstudied populations).

Causal models are falsifiable, in that if they do not match data, they must be rejected as invalid. They must also be credible to those close to the phenomena the model intends to explain.

If the resulting model is simple enough, it may be possible to use mathematical methods (such as algebra or calculus) to obtain exact information on the system of interest via an analytical solution. However, please note that 'exact' refers to the model, not to reality as there is usually a gap between both, for example because of simplification or abstraction.

As an example, take the distance travelled by a falling object: The distance s travelled by objects during the first t seconds of free fall is described by the well-known formula

$$s = 1/2gt^2,$$

where g is the gravity acceleration

$$(g = 9.81\frac{m}{s^2} \text{ on earth}).$$

This model describes very well the movements of objects that are comparably heavy (like stones or apples). However, it becomes inaccurate for objects whose air resistance is quite big compared to their weight (such as feathers).

2.4 Simulation Models

Simulation models are a special kind of forecasting models for complex systems, where it is impossible to capture the system's behaviour as a whole analytically, often because of stochastic influences and complex relations between the system's elements. Instead, computers are used to *imitate*, or simulate, the system. To do so, the behaviour of each element is specified. When the simulation is run, the computer tracks each element and imitates its behaviour. Finally, quantitative performance indicators are collected and reported.

Simulation models often involve stochastics. In this case, the result of a single simulation run is more or less meaningless and the simulation is run multiple times to calculate valid averages (i.e. that come close to their expected values because of the law of large numbers) and determine confidence intervals etc. for the performance indicators of interest. While simulations implied a lot of manual coding in the past, modern software packages recently rendered this process much more user friendly.

A die, for example, is simulated by drawing a random number between 1 and 6. To obtain its expected value, this is repeated a hundred times and the following frequencies are recorded: 1: 15, 2: 17, 3: 14, 4: 18, 5: 20, 6: 16. Summing up leads to 359, that is, an average of 3.59.

Note that this example is so simple that we would usually not use simulations to approximate the die's expectation but rather use probability theory to exactly determine it:

$$\sum_{i=1}^{6} \frac{1}{6} \cdot i = 3.5.$$

This is also a nice example for the limitations of an exact, analytical solution: 3.5 is obviously the expectation of the die in our model. But clearly not of any real-world die: because of mechanical defects or deviations during the production process, the real-world die will not have exactly equal probabilities.

There are many features of simulations we cannot capture with the space available here. However, we would like to briefly describe two special types of simulations that enjoy an increasing popularity (see Law 2015 for an in-depth introduction to simulation).

Agent-based Simulation

Agent-based simulation (ABS) is comparably new and gained popularity through a tutorial and a dedicated track at the 2005 Winter Simulation Conference. However, there is no generally accepted definition of an agent or ABS. Lots of concepts are associated with ABS, but it is not clear what is at its heart.

An *agent* is an autonomous entity that can sense its environment, including other agents, and use this information in making decisions. In particular, agents have attributes and a set of *rules that determine their behaviours*. Some may have a memory and learn over time. Agents may include people, animals, vehicles, and organizations. Often, an ABS is defined as a simulation where agents interact with each other and their environment in a major way.

In ABS, a *bottom-up approach* to modelling is taken, where the emphasis is on describing the behaviour and interaction of the individual agents. In some ABS, the interactions of the agents over time result in emergent behaviour of the system as a whole, which is not deducible from the characteristics of the individual agents.

Introductions to ABS include Law (2015, Ch. 13.2) as well as Deckert and Klein (2010). They also briefly describe popular software packages like AnyLogic. (For details on ABS, see also Weyer et al. in this volume.)

System Dynamics

System Dynamics (SD) is a type of simulation that is often used for designing and improving policies or strategies in business, government and the military. In contrast to ABS, it is a *top-down* approach to modelling a system. SD models look at systems at a more *aggregate level* and are used for strategic decisions. The majority of models is deterministic, but random components are also possible. SD was created by Professor Jay Forrester at MIT in the 1950s.

Common components of an SD model are *stocks* (an accumulation of a resource), *flows* (streams of a resource into or out of a stock) and *information links* (brings information from a stock to the valve of a flow). For more details, the reader is referred to Law (2015 Ch. 13.3).

2.5 Optimization Models

An optimization model adds an *objective function* to one of the aforementioned model families to *rate* (predicted) outcomes or system states. Evaluating the model for different decision alternatives thus allows selecting the preferred one. Optimization models are a formal representation of optimization problems, where the *best alternative* is selected with regard to the defined goals.

Scientists usually formulate optimization models using mathematical formulae and seek so-called closed-form solutions. As an example, we may take a landscaper who designs a public park with a rectangular lawn surrounded by a row of roses. She wants in total 100m of roses, and she prefers the lawn as big as possible. How long should she choose both sides of the lawn? This optimization problem is represented by the following optimization model:

$$\max_a f(a) \text{ with } f(a) = a \cdot (50 - a),$$

where we use that the length of both sides of the lawn must sum up to 50m. The problem is solved with basic calculus as:

$$f'(a) = -2a + 50 = 0 \Longleftrightarrow a = 25 \text{ and } f''(a) = -20.$$

Thus, a square lawn with an edge length of 25m is optimal for her.

More complex optimization problems make the relations between causal models and optimization more obvious. Here, we may take the example of a farmer's crop choice: A farmer disposes of two fields of land. Field A is 20 ha in size, field B 10 ha. He can plant corn or wheat. Field A is slightly more fertile than B. He expects a profit of 11€/ha from corn and 9€/ha from wheat on field A and 10€/ha for corn and 9€/ha for wheat on field B. Because of long-term contracts, he must at least produce wheat equal to 5 ha. Let c_A denote the amount of corn (in ha) on field A and c_B on field B. Likewise, the wheat planted is denoted by w_A and w_B.

$$\max_{c_A,c_B,w_A,w_B} 11 \cdot c_A + 10 \cdot c_B + 9 \cdot (w_A + w_B) \quad (1)$$

$$c_A + w_A \leq 20 \quad (2)$$

$$c_B + w_B \leq 10 \quad (3)$$

$$w_A + w_B \geq 5 \quad (4)$$

$$c_A, c_B, w_A, w_B \geq 0 \quad (5)$$

Here, (1) is the objective function that allows to rate a state of the system. (2)-(5) is a causal model that describes restrictions a feasible solution must satisfy. We must admit that to save space, the problem is so simple we can find an optimal solution without any advanced technique:

$$c_A = 20, c_B = 5, w_A = 0, w_B = 5$$

with a total profit of 315 €.

In contrast to the previous example, more complex problems can usually not be solved with basic calculus from secondary school. To choose an appropriate solution technique, the model type is important. The crop choice example is a so-called linear model and thus comparably easy to solve exactly using, for example, the widespread simplex algorithm invented by the US mathematician George Dantzig in 1947. For other model types, other techniques may be necessary. Sometimes an exact solution (in the mathematical sense) cannot be found, but numerical approaches find arbitrarily good solutions. Optimization models are at the heart of operations research, see, for example, Taha (2016) for an introduction.

In other cases, it may be too complicated or even impossible to capture the system's mechanics in mathematical formulae as we did in (2)–(5) of the crop choice example. In this case, a simulation model may be used instead of formulae to represent the system.

Scenarios, Decision Support, and Simulation-based Optimization

Simulations predict the evolution or behaviour of the system modelled. Thus, at their heart, they do *not* provide decision support. However, simulations can be repeated with different initial parameter values to predict the system's behaviour for an alternative scenario. If the scenarios correspond to decision alternatives, simulation can be used to evaluate the alternatives and select the most preferred one according to an objective function (e.g., think of simulating traffic in a city centre with a new tunnel with one or two lanes).

Clearly, the evaluation of each scenario as described above is only possible if their number is low (often five to ten). For example, a traveling salesman who wants to visit 11 customers already has 19,958,400 sequences to choose from. For such problems with a large number of or even continuous alternatives (like global warming given yearly future CO_2 emissions), complete enumeration is impossible. Instead, simulation-based optimization (SBO) approaches are used. These iterative approaches usually simulate a few scenarios and derive approximate relations between the decision variables (the parameters that can be varied) and the objective function. Based on this, they make an 'educated guess' which variable values may lead to a better objective. This guess is then tested with new simulations, which starts a new cycle with improving the derived approximate relation, based on which a new guess is made. Over the years, countless mathematical approaches have been developed to realize this (see, e.g., Gosavi 2015 or Fu 2015). To be precise, simulation-based optimization is not a model, it is a solution approach that uses simulation to solve optimization problems.

3. Texts as Qualitative Models

3.1 Limitations of Quantitative Models from a Cultural Studies Perspective

Quantitative models are characterised by abstraction and aggregation and thus are generally not concerned with local or individual specificity. Despite their undisputed achievements in dealing with a range of aspects of urban complexity – demographic developments, material and energy flows, mobility planning and innumerable others – it is in understanding qualitative phenomena – such as urbanity, individuality, place-specificity, individual patterns of interpretation and sense-making – that quantitative models show their limitations. For although it is, of course, possible to include certain 'subjective' features into a model (for instance by including group-specific cultural preferences, as is common in agent-based modelling and other types of urban simulation models), what is individual, unique, historically and personally specific and not reducible to an underlying pattern, is what disappears in abstracting from the individual and in the aggregation of preferences, needs, desires, hopes, fears into an equation (for a brief discussion of these limitations, cf. also Gurr 2021, 15–19).

3.2 Analysing Urbanity, Individuality, Local Specificity: Texts as Qualitative Urban Models

This is where texts can play a role as a specific type of complementary qualitative model: It is precisely this individuality and specificity both of different urban environments in their "intrinsic logic" (*sensu* Berking/Löw 2008) and of human behaviour, of perceptions and patterns of sense-making that literary texts model in uniquely differentiated ways. It is in literary texts that the "non-sensual" city of sociologists (*sensu* Lindner 2006) and quantitative modellers becomes perceptibly individualised.

Here, the inquiry into the "knowledge *of* literature" (cf. Hörisch 2007; our italics) or into the strategies of producing knowledge *in* literature may be especially relevant: What are the specific achievements of literature and of literary texts as a unique form of generating, storing, transmitting and mediating knowledge (cf., for instance, Fluck 1997; Gymnich/Nünning 2005; Felski 2008; Gurr 2013)? It has been argued that literary texts represent knowledge – or create it in the first place – in ways fundamentally different from discursive, expository texts (cf., for instance, Glomb/Horlacher 2004; Hörisch 2007). Specific literary strategies thus become "devices for articulating truth" (Felski 84). This centrally concerns questions of genre and questions of literary modelling generally: In which ways do literary texts function differently from discursive texts on the same subject (for an example, cf. Gurr 2017) or what are the specific cognitive achievements of narrative as opposed to, say, quantitative models of complex matters?

With reference to the relation between the city and the text, a text can thus be understood as a qualitative urban model in that it is – again to varying degrees – *descriptive* in its representation of the city and – again at least implicitly – *prescriptive* in that it formulates directions or options for a different future city. This dual nature is also evident in the fact that texts not only represent an external urban reality but contribute to shaping perceptions of the urban and thus to highlighting that a different city is at least conceptually possible. Moreover, as the increasingly frequent collaboration between planning experts and science fiction writers shows, literary texts as models *of* and models *for* urban realities also have a crucial role to play in developing scenarios.[1] What literary and cultural studies can contribute here is an understanding of precisely those elements of urban complexity that cannot be measured, modelled, classified in quantitative terms.

When it comes to defining elusive notions such as 'urbanity' or 'metropolis', for example, purely quantitative models can be shown to be of limited use: 'Metropolis' and, to a lesser extent, 'city', it seems, are not merely designations that are tied to quantitative criteria; they are not solely descriptive terms, but more or less strongly imply normative elements, even a utopian promise – and this is largely a cultural promise that is difficult to categorise or quantify. However, the concept of the metropolis of course is not only normative. It does make sense to classify cities according to various criteria, and many historical as well as recent attempts to define the metropolitan character of cities are very enlightening.[2] Thus, the concept of 'metropolis' – just like 'urbanity' – curiously oscillates between descriptively designating a quantifiable status of centrality as a financial centre, a traffic node, a centre of research and education or of the media industry on the one hand, and a normative requirement of a far less tangible metropolitan 'feel' of cultural promise (cf. Gurr 2010, 2015): Frankfurt/M. may be a financial metropolis, because, second to London, it is the seat of the most important European stock exchange and of several important banks, but is it, on a global scale, a cultural metropolis? Berlin, although certainly not a financial centre, is a metropolis, because it is a capital with over three million residents, but it also appears to have the intangible cultural 'flair' a metropolis in the wider sense also seems to need. The urban novel, for instance, in the panoramic representation of social interactions as well as individual responses to specific cities or metropolitan regions, can here be shown to function as an alternative form of 'modelling' urban complexity.

3.3 Case Study: Modelling the Complexities of the Ruhr Region in a Novel

As a case in point, we might take Jürgen Link's 2008 novel *Bangemachen gilt nicht auf der Suche nach der Roten Ruhr-Armee: Eine Vorerinnerung*. The title translates into something like "Don't Be Intimidated in Search of the Red Ruhr Army: A Pre-Memory", the Red Ruhr Army being a reference to the left-wing worker's army which, since March 1920, defended the early Weimar Republic against reactionary and anti-republican forces after the right-wing Kapp-Putsch. In over 900 pages, the text on the one hand is a fictionalised (if sometimes thinly veiled) collective biography of a group of 'old leftists', "non-

1 Thus, the German Federal Institute for Building, Urban and Spatial Research (BBSR) in 2015 issued a study entitled *Learning from Science Fiction Cities: Scenarios for Urban Planning* (our translation; cf. BBSR).

2 Cf. especially Danielzyk and Blotevogel, who distinguish between the (1) innovation and competition function, (2) decision and control function, (3) gateway function, and (4) symbolic function. For an early influential study, cf. Hall 1966; for a widely debated recent contribution, cf. Sassen; for a survey, cf. Bronger. Cf. also Terfrüchte in this volume.

renegade members of the 68 generation"[3] (Link 2008, 881; translation JMG) in the Ruhr region from the 1960s to the early 2000s. On the other hand, it is an attempt at representing the complex topography of the Ruhr region and its multiple historical layers in a structurally and conceptually – and often stylistically – highly complex novel:

> The route changes in its combinations of bits of *autobahn* and alleged short-cuts, that is labyrinthically curving residential neighbourhood streets or transition roads from the last suburb of the previous Ruhr city to the 1st suburb of the next; traffic jams increase or intermittently decrease in parallel with construction noise and the economic situation; the airstream of the cars in front of you whirls up shreds of tabloid papers from the ditch and sometimes a completely empty car with flashing alarm lights stands on the right curb [the sentence continues for eight more lines] (Link 2008, 28; translation JMG).
> The Turkish colleague had to brake hard: right on this stretch of commercial street through which we then had to commute on our way to work, felt reminded of France every time: broad and splendid it went on for several 100 metres straight on and slightly uphill between glaring and pleasantly renovated façades in all sorts of Krupp styles: from Krupp Romanesque via Krupp Gothic all the way to Krupp Renaissance and Krupp Baroque, in which large shop windows flashed, facades, and nothing behind them [again, the sentence continues for several more lines]. In the evenings, as is typical of the Ruhr region, such brightly lit neighbourhoods with shop windows and shiny tube station entrances abruptly alternated with gloomy stretches, where, to the left and to the right, there were still fields, before it just as abruptly became bright again, but this time as if we had entered the inside of a production site, where bright lights were supposed to protect a mix of new plastic halls and old brick buildings against gangs of burglars. (Link 2008, 37f.; translation JMG)[4]

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3 The novel professes to be "a realistic report on the experiences of a group of non-renegade members of the 68 generation" (Link 2008, 881; my translation); the German original reads: "realistische[r] Erfahrungsbericht einiger nichtkonvertierter 68er".

4 The German original reads: "Die Route wechselt in ihren Kombinationen von Autobahnstücken und angeblichen Schleichwegen will sagen sich labyrinthisch biegenden Wohnviertelstraßen oder Überbrückungspisten vom letzten Vorort der letzten Ruhrstadt zum 1. Vorort der nächsten, die Staus nehmen weiter zu oder zwischendurch wieder etwas ab parallel mit dem Baulärm und mit der Konjunktur, der Fahrtwind der Wagen vor Euch wirbelt Schlagzeitungsfetzen in der Gosse auf und manchmal steht ein vollständig leeres Auto mit blinkendem Alarmlicht am rechten Straßenrand [der Satz geht noch über acht Zeilen weiter]." (Link 2008, 28) "Der türkische Kollege musste voll auf die Bremse treten: mitten auf diesem Stück Geschäftsstraße, durch das wir damals pendeln mussten auf dem Weg zur Arbeit, uns jedesmal wieder erinnert an Frankreich: breit und prächtig ging es ein paar 100 Meter schnurgerade und leicht bergauf zwischen knallig und schön renovierten Fassaden in allen möglichen Kruppstilen: von Kruppromanik über Kruppgotik bis hin zu Krupprenaissance und Kruppbarock, worin überall große Schaufenster blitzten, Fassaden und nichts dahinter […]. Abends wechselten, wie es typisch im Ruhrgebiet ist, solche hell erleuchteten Viertel mit Schaufenstern und glitzernden U-Bahn-Eingängen abrupt mit finsteren Abschnitten, wo rechts und links noch Felder waren, bevor es ebenso abrupt wieder hell wurde, aber diesmal wie als ob wir ins Innere eines Werksgeländes geraten wären, wo helle Laternen ein Gemisch aus neuen Plastikhallen und alten Ziegelbauten gegen die Einbrecherbanden schützen sollten." (Link 2008, 37f.)

In an interview, but also in an essay on his own novel, Link comments on the function of these complex structures as follows: "The Ruhr region is one of the very few conurbations that are structured like a rhizome" (Heidemann n.p.).[5] Thus, in keeping with the original biological meaning of the term 'rhizome' as a multifariously interconnected network of roots, the concept as established by Deleuze and Guattari also designates a web of interconnections without a tree-like hierarchy. As an organisational structure in which, to put it simplistically, 'everything is connected to everything else', as a symbol of a non-hierarchical organisation of knowledge, such a decentralised structure also implies a moment of resistance against dominant, authoritarian and hierarchical forms of organising knowledge and of exercising power.

Thus, it is not least on the micro-level of its individual endlessly meandering sentences that the novel simulates the heterogeneous *spatial* structures, layers and interdependencies of and in the region. Yet, as the above passage with its reference to a succession of "Krupp styles" makes clear, the novel also subtly engages with *temporal* layers, both in such individual passages and in its overall structure, which frequently includes so-called "simulations", often highly political projections of the future from previous decades, which are then explicitly or implicitly checked against actual developments as they *did* take place. However, the palimpsestuous nature of the region, its spatialized layered memory, is arguably even more centrally represented through the individual and collective recollections of the protagonists and in the forms and locations in which these recollections physically manifest themselves and through which, in turn, they are kept alive and are invoked.

A recurring image that is in keeping with the frequent references to the region's mining past is that of consciousness and memory as functioning in layers that are explicitly referred to as the levels of a mine (cf. fig. 4.15), for instance in a reference to "all five levels of our pit of consciousness" (Link 2008, 398; translation JMG):

> though in that brief moment of saturation before falling asleep we may have felt an insight flit through our brains – during our walks through the colliery grounds, again and again, a further clarity of insight had temporarily come into our heads, accompanied by multivocal simultaneous awareness of the various levels in our heads, sometimes almost down to the lowest, the 5th level. (Link 2008, 398; my translation; cf. also 711, 721)[6]

Moreover, the novel frequently stages the layering of the region by referring to the temporal succession of dominant industries on specific sites, not least in numerous references to car manufacturing as the major industry that has taken over from mining.

5 The German original reads: "Das Ruhrgebiet ist eines der ganz wenigen Ballungsgebiete, die wie ein Rhizom strukturiert sind." (Heidemann n.p.)

6 The German original reads: "alle 5 Sohlen unseres Bewusstseinspütts" (Link 2008, 398): "mochten wir dann im kurzen Moment des Sattseins vor dem Einschlafen noch eine Einsicht durch die Gehirne huschen fühlen – so war bei den Spaziergängen im Zechengelände immer wieder zeitweise eine noch zusätzliche Durchblicksklarheit in unsere Köpfe gekommen, wozu ein mehrstimmiges simultanes Bewusstsein der verschiedenen 'Sohlen' in unseren Köpfen gehört hatte, manchmal fast bis auf die unterste, 5. Sohle herab." (Link 2008, 398).

Thus, in the course of the novel, there are some 40 references to "Ruhr-Motor", sometimes also referred to as "Inter-Ruhr-Motor", which is clearly recognisable as a reference to the Opel plants in Bochum. Occasionally, the text even directly refers to the succession of industries on the same site: "'He had been working in mine Gneisenau Two […] where now there is plant 3 of Ruhr Motor'" (Link 2008, 370; my translation).[7] This passage is also telling in its use of specific place names: "Zeche Gneisenau" was in fact a coal mine in Dortmund, but it seems to be typical of the novel to obscure, blur or amalgamate concrete place references in order all the more strongly to suggest an overarching 'Ruhr local colour' at the same time.

In sum, Link's novel thus lends itself to exemplifying both the importance of the unique spatial structures of the Ruhr region *and* its temporal layers.

3.4 Literary Texts as Qualitative Simulation Models

Somewhat speculatively, we might argue that literary texts as models of reality are *per se* combinations of order and disorder: In frequently highly structured and ordered ways, they represent complexity and multiplicity, even disorder, and overlay disorder with order – established plot structures, schemata, or typological patterns of interpretation (cf. Koschorke 29ff.) – and thus structurally replicate key patterns of urban complexity (for a detailed discussion of texts as structural and functional urban models, cf. Gurr 2021).

Moreover, if 'scenario building' and the testing of alternative parameter settings in their impact on a given system is regarded as a crucial function of urban systems modelling, then a parallel with an important type of quantitative model (see 2.5 above) emerges: One of the central functions of literature, according to one understanding, is that it serves as a form of symbolic action, as a social experiment free from the constraints of everyday life – literature as 'depragmatised behaviour in rehearsal' ['entpragmatisiertes Probehandeln'][8] which makes it possible symbolically to try out in fiction different scenarios or potential solutions for key societal issues. Here, too, given the descriptive, representational as well as the – at least implicitly – prescriptive, speculative, exploratory function of texts, this conceptualisation – developed in the wake of Mahr's understanding of the model – of texts as both descriptive "models *of*" and prescriptive "models *for*" urban structures, developments and functions, seems highly appropriate.

4. Conclusion: Intersections and Parallels between Quantitative and Textual Models

A key issue that needs to be addressed in comparative discussions of quantitative and verbal urban models is the fundamentally different status of the 'model' in both fields:

7 The German original reads: "'Der hatte da auf Zeche Gneisenau Zwo gearbeitet […] wo jetzt Werk 3 von Ruhr-Motor steht.'" (Link 2008, 370).

8 This is the view formulated, among others, by Kenneth Burke, Dieter Wellershoff, Wolfgang Iser or Glomb/Horlacher.

While in technical urban complexity research, the model is the *result* of scientific endeavour, in literary and cultural studies, the literary text functions as the 'model' and is thus the *object of study* rather than the *result* of the scholar's own work. Thus, Mahr's rather casually enumerative formulation of the two alternative ways in which models come into being – "no object is a model per se. Models are *built* or *chosen*" (331; italics original) – here constitutes a fundamental distinction between different research cultures and their dominant forms of engaging with models.

Despite the fundamentally different status of the 'model' in urban complexity modelling on the one hand and in literary and cultural studies on the other hand, there are a number of important parallels and points of intersection between the two types of 'model' and in the understanding of complexity: What most technical notions of complexity share is that they measure the complexity of a system in terms of the length or the complexity of the description or representation of that system. A number of complexity theorists have even argued that "complexity is not primarily a characteristic of the object that is being described, but of the description" (Richter/Rost 112; my translation).[9] This notion might lend itself as a bridge between technical or mathematical and cultural conceptualisations of complexity. Ultimately, what is relevant to literary studies, one might argue, is not so much the complexity of the city itself, but the representation of this complexity, i.e., its description in the 'model' of the literary text. Literary studies are thus concerned with the challenge of 'modelling' it, or, in the terminology of literary studies, of 'representing' it. Thus, where technical and mathematical complexity research is concerned with the mathematical description of complexity, literary and cultural studies of urban complexity are concerned with the challenges of verbal representation.

Gell-Mann's notion of "effective complexity" provides an important connection between a technical and a literary understanding of complexity:

> A measure that corresponds much better to what is usually meant by complexity in ordinary conversation, as well as in scientific discourse, refers not to the length of the most concise description of an entity (which is roughly what AIC [algorithmic information content] is), but to the length of a concise description of a set of the entity's regularities. Thus something almost entirely random, with practically no regularities, would have effective complexity near zero. So would something completely regular, such as a bit string consisting entirely of zeroes. Effective complexity can be high only in a region intermediate between total order and complete disorder. (1995, 16)

This seems precisely to be the case with cities and, even more so, metropolitan regions: In the sense of "effective complexity", they are systems in which there are multiple regularities as well as contingencies, and hence systems in which "a concise description of a set of the entity's regularities" would be extremely long. Thus characterised by an intricate combination of both order and disorder, cities have long been understood as systems of extremely high "effective complexity" (take Jane Jacobs's classic formulation that cities are "problems in organized complexity", 449).

9 The German original reads: "Komplexität ist nicht in erster Linie eine Eigenschaft des beschriebenen Objekts, sondern der Beschreibung selbst." (Richter/Rost 112).

The different procedures used in different fields and disciplines to represent, reduce (or: constitute in the first place) and seek to 'manage' complexity do justice to different facets of urban complexity in varying degrees: Mobility systems or energy flows lend themselves to quantitative models far better than do processes of sense-making or conflicting patterns in the perception and use of space, which find privileged expression in verbal models of literary texts. Even the selection criteria for facets to be included in (and, conversely, excluded from) the model are virtually diametrically opposed: that which is individual, specific or characteristic in literary texts as opposed to that which can be generalised, aggregated and quantified in quantitative models.

Moreover, the boundaries between numerical, visual and narrative models do not necessarily coincide with disciplinary boundaries, as the example of modelling urban complexity in social cartography shows (for a detailed discussion cf. Gurr/Schneider; for questions of statistics and cartography, cf. Schneider 2006, 2011a, 2011b, 2014; for mapping in literary studies, cf. Mattheis 2021, 83–133; Moretti 1998; Rosseto 2014): Here, visualisations are regularly preceded by quantitative models, which in turn may be informed by underlying – often unquestioned – narratives. Similar forms of overlay and transfer between quantitative and visual models are to be found in different methods of mathematical optimisation such as graph theory or in the geometrical tesselation of areas as they occur in the optimisation of infrastructures, logistics networks, scheduling problems or evacuation scenarios. What is more, qualitative and quantitative representations of complexity by no means have to correspond: some forms of complexity may be easy to describe qualitatively but may be extremely difficult to quantify (and vice versa).

Nonetheless, a number of strategies in dealing with complexity are rather similar, and there are a large number of overlaps, interactions and transfers between different basic types of models. There are, for instance, a number of remarkable parallels and analogies between algorithmic and aesthetic/literary strategies of representing and reducing complexity (sometimes only reduction may make representation possible in the first place). Thus, a number of literary strategies of reducing complexity – for instance, the metonymic strategy of telling one story and suggesting that innumerable others would also have been worth telling, or the breaking of linearity by means of partition and distribution (for a typology of such strategies, cf. Gurr 2021) – are paralleled in mathematics and information technology in the handling of complex calculations and large quantities of data by means of distributed computing, randomisation or decomposition (for an accessible discussion, cf. Schulz).[10]

Despite such parallels, analogies and processes of exchange, the different methods of modelling complexity cannot be seamlessly integrated or converted into one another: Rather, the different types of model might be seen to complement each other, for instance by mutually offsetting shortcomings and by filling in each other's blind spots.

10 Some of this part goes back to discussions with Alf Kimms, professor of Logistics and Operations Research at the University of Duisburg-Essen's Mercator School of Management, in a previous project.

This kind of integration of various approaches to modelling, we argue, is crucial to a more refined understanding of complex metropolitan structures and systems.[11]

5. Works Cited

Albeverio, Sergio, Denise Andrey, Paolo Giordano, Alberto Vancheri (eds.). The Dynamics of Complex Urban Systems: An Interdisciplinary Approach. Heidelberg: Physica, 2008.

Batty, Michael. "Cities as Complex Systems: Scaling, Interaction, Networks, Dynamics and Urban Morphologies." Encyclopedia of Complexity and Systems Science. Ed. Robert A. Meyers. Berlin: Springer, 2009. Vol. 1, 1041–1071.

Batty, Michael. The New Science of Cities. Cambridge, MA: MIT Press, 2013.

BBSR – Bundesinstitut für Bau-, Stadt- und Raumforschung. Von Science-Fiction-Städten lernen: Szenarien für die Stadtplanung. Bonn: BBSR, 2015.

Berking, Helmuth, Martina Löw (eds.). Die Eigenlogik der Städte: Neue Wege für die Stadtforschung. Frankfurt am Main: Campus, 2008.

Brockwell, Peter J., Richard A. Davis. Introduction to Time Series and Forecasting. New York: Springer, 2016.

Bronger, Dirk. Metropolen – Megastädte – Global Cities: Die Metropolisierung der Erde. Darmstadt: Wissenschaftliche Buchgesellschaft, 2004.

Burke, Kenneth. The Philosophy of Literary Form: Studies in Symbolic Action. Berkeley: University of California Press, 1974 [reprint; orig. ed.: Baton Rouge: Louisiana State University Press, 1941].

Danielzyk, Rainer, Hans Heinrich Blotevogel. "Leistungen und Funktionen von Metropolregionen." Metropolregionen und Raumentwicklung, Part 3: Metropolregionen. Innovation, Wettbewerb, Handlungsfähigkeit. Ed. Jörg Knieling. Hannover: Verlag der ARL, 2009. 22–29.

Deckert, Andreas, Robert Klein. "Agentenbasierte Simulation zur Analyse und Lösung betriebswirtschaftlicher Entscheidungsprobleme." Journal für Betriebswirtschaft 60 (2010): 89–125. http://doi.org/10.1007/s11301-010-0058-6.

Eckardt, Frank. Die komplexe Stadt: Orientierungen im urbanen Labyrinth. Wiesbaden: Verlag für Sozialwissenschaften, 2009.

Felski, Rita. Uses of Literature. Oxford: Blackwell, 2008.

Fluck, Winfried. Das kulturelle Imaginäre: Eine Funktionsgeschichte des amerikanischen Romans, 1790–1900. Frankfurt am Main: Suhrkamp, 1997.

Fu, Michael (ed.). Handbook of Simulation Optimization. New York, Heidelberg, Dordrecht, London: Springer, 2015.

Gell-Mann, Murray. "What is Complexity?" Complexity 1.1 (1995): 16–19.

Glomb, Stefan, Stefan Horlacher (eds.). Beyond Extremes: Repräsentation und Reflexion von Modernisierungsprozessen im zeitgenössischen britischen Roman. Tübingen: Narr, 2004.

11 Sections 1, 3 and 4 partly reuse material developed in Gurr 2021.

Gosavi, Abhijit. Simulation-Based Optimization: Parametric Optimization Techniques and Reinforcement Learning. New York: Springer, [2]2015.

Gurr, Jens Martin. Charting Literary Urban Studies: Texts as Models of and for the City. New York: Routledge, 2021.

Gurr, Jens Martin. "'Without contraries is no progression': Emplotted Figures of Thought in Negotiating Oppositions, Funktionsgeschichte and Literature as 'Cultural Diagnosis'." Text or Context: Reflections on Literary and Cultural Criticism. Ed. Rüdiger Kunow, Stephan Mussil. Würzburg: Königshausen & Neumann, 2013. 59–77.

Gurr, Jens Martin. "Views on Violence in Shelley's Post- Peterloo Prose and Poetry: Contradiction, Ambivalence, Ambiguity?" Romantic Ambiguities: Abodes of the Modern. Ed. Sebastian Domsch, Christoph Reinfandt, Katharina Rennhak. [Studies in English Romanticism 20]. Trier: WVT, 2017. 83–93.

Gurr, Jens Martin, Ute Schneider. "Strategien zur Bewältigung urbaner Komplexität: Zum Zusammenwirken visueller, verbaler und quantitativer Modelle." Komplexität und Einfachheit: DFG-Symposion 2015. Ed. Albrecht Koschorke. Stuttgart: Metzler, 2017. 256–275.

Gymnich, Marion, Ansgar Nünning (eds.). Funktionen von Literatur: Theoretische Grundlagen und Modellinterpretationen. Trier: WVT, 2005.

Hall, Peter. The World Cities. London: Weidenfeld & Nicolson, 1966.

Hendry, David, Jennifer Castle, Michael Clements. Forecasting: An Essential Introduction. New Haven: Yale University Press, 2019.

Hörisch, Jochen. Das Wissen der Literatur. Munich: Fink, 2007.

Iser, Wolfgang. Das Fiktive und das Imaginäre: Perspektiven literarischer Anthropologie. Frankfurt am Main: Suhrkamp, 1993.

Koschorke, Albrecht. Wahrheit und Erfindung: Grundzüge einer Allgemeinen Erzähltheorie. Frankfurt am Main: Fischer, [3]2013.

Law, Averill. Simulation Modeling and Analysis. New York: McGraw-Hill (2015).

Lindner, Rolf. "Textur, 'imaginaire', Habitus. Schlüsselbegriffe der kulturanalytischen Stadtforschung." Die Eigenlogik der Städte: Neue Wege für die Stadtforschung. Ed. Helmuth Berking, Martina Löw. Frankfurt am Main: Campus, 2008. 83–94.

Mahr, Bernd. "Modelle und ihre Befragbarkeit: Grundlagen einer allgemeinen Modelltheorie." Erwägen – Wissen – Ethik/Deliberation – Knowledge – Ethics: Forum für Erwägungskultur/Forum for Deliberative Culture 26.3 (2015): 329–342.

Mainzer, Klaus. Thinking in Complexity: The Computational Dynamics of Matter, Mind and Mankind. Berlin: Springer, [5]2007.

Mattheis, Lena. Translocality in Contemporary City Novels. Cham: Palgrave Macmillan 2021.

Moretti, Franco. Atlas of the European Novel, 1800–1900. London, New York: Verso. 1998.

Portugali, Juval. "Complexity Theories of Cities: Achievements, Criticism and Potentials". Complexity Theories of Cities Have Come of Age: An Overview with Implications to Urban Planning and Design. Ed. Juval Portugali, Han Meyer, Egbert Stolk, Ekim Tan. Springer Complexity. Berlin, Heidelberg: Springer, 2012a. 47–62.

Portugali, Juval. "Introduction." Complexity Theories of Cities Have Come of Age: An Overview with Implications to Urban Planning and Design. Ed. Juval Portugali, Han

Meyer, Egbert Stolk, Ekim Tan. Springer Complexity. Berlin, Heidelberg: Springer, 2012b. 1–5.

Portugali, Juval. Complexity, Cognition and the City. Understanding Complex Systems (UCS). Berlin, Heidelberg: Springer, 2011.

Portugali, Juval. "Complexity Theory as a Link Between Space and Place." Environment and Planning A 38 (2006): 647–664.

Richter, Klaus, Jan-Michael Rost. Komplexe Systeme. Frankfurt am Main: Fischer, 2002.

Rossetto, Tania. "Theorizing Maps with Literature." Progress in Human Geography 38.4 (2014): 513–530.

Sassen, Saskia. The Global City: New York, London, Tokyo. Princeton: Princeton University Press, ^{2}2001.

Schneider, Ute. "Inquiries or Statistics? Agricultural Surveys and Methodological Considerations in the Nineteenth Century." The Golden Age of State Enquiries. Ed. Nadine Vivier. Turnhout: Brepols, 2014. 43–57.

Schneider, Ute. "Die Farbe der Religion: Topographie und Topik der 'Deux France'." Journal of Modern European History 9 (2011a): 117–139.

Schneider, Ute. Die Macht der Karten: Eine Geschichte der Kartographie vom Mittelalter bis heute. 3rd enl. and updated ed. Darmstadt: Primus, 2011b.

Schneider, Ute. "'Den Staat auf einem Kartenblatt übersehen!' Die Visualisierung der Staatskräfte und des Nationalcharakters." Kartenwelten: Der Raum und seine Repräsentation in der Neuzeit. Ed. Christof Dipper, Ute Schneider. Darmstadt: Primus, 2006. 11–25.

Stachowiak, Herbert. Allgemeine Modelltheorie. Vienna/New York: Springer, 1973.

Taha, Hamdy A. Operations Research: An Introduction (10th edition). Harlow/London/New York: Pearson, 2019.

Wellershoff, Dieter. Literatur und Lustprinzip. Cologne: Kiepenheuer & Witsch, 1973.