Simulation Modeling for Planning Regional Accessibility: A Complex Systems Approach

Victoria Kazieva

Main supervisor: Aron Larsson

Co-supervisor: Christine Große

Faculty of Science, Technology and Media

Thesis for Licentiate Degree in Information Systems

Mid Sweden University

Sundsvall, 2025-02-03

Akademisk avhandling som med tillstånd av Mittuniversitetet i Sundsvall framläggs till offentlig granskning för avläggande av filosofie licentiatexamen måndag, 03 februari, 13:00, C312, Mittuniversitetet i Sundsvall. Seminariet kommer att hållas på engelska.

Simulation Modeling for Planning Regional Accessibility: A Complex Systems Approach

© Victoria Kazieva, 2025-02-03

Printed by Mid Sweden University, Sundsvall

ISSN: 1652-8948

ISBN: 978-91-89786-91-2

Faculty of Science, Technology and Media
Mid Sweden University, SE-851 70 Sundsvall
Phone: +46 (0)10 142 80 00

Mid Sweden University Licentiate Thesis 208

All models are wrong, but some are useful.
–George Box, "Science and statistics", 1976

When people thought the Earth was flat, they were wrong.
When people thought the Earth was spherical, they were wrong.
But if you think that thinking the Earth is spherical is just as
wrong as thinking the Earth is flat, then your view is wronger
than both of them put together.
–Isaac Asimov, "The Relativity of Wrong", 1989

Acknowledgments

First and foremost, I would like to thank my main supervisor Aron Larsson for the opportunity, support, and challenging discussions we shared during this journey.

I owe special gratitude to my co-supervisor, Christine Große, who inspired me, helped me find my way, write, doubt, and explore, and contributed a lot to my development.

I thank Ida Kristoffersson for taking the time to review my work and providing valuable insights that substantially improved it, paving the way for future endeavors.

I want to give special thanks to my kind and supportive colleagues—Leif Olsson, Annika Hasselblad, and Niklas Humble—without whom this journey would not have been the same, either professionally or through their encouragement and much-needed conversations.

I'm very appreciative of our growing group of doctoral students and look forward to more opportunities to exchange ideas and share time together: Erica, Lisa, Per, Joakim, Eric, Natalie, Marcus, and Maya.

Most importantly, I am eternally grateful to my biggest encouragers—my family, especially my mom and Svenne, for supporting me in my decision to embark on this wobbly, scary, yet greatly rewarding journey. I am lucky to have you, who urge me to dream big.

Table of contents

Acknowledgments ..... **v**

List of Figures ..... **ix**

List of Tables ..... **ix**

Keywords ..... **ix**

Abstract ..... **xi**

Summary in Swedish ..... **xiii**

List of Included Papers ..... **xv**

Introduction **1**

1.1 Motivation 1

1.2 Why the Sundsvall's Region? 2

1.3 Evolution of Problem Formulation 3

1.4 Objective and Research Questions 7

1.5 Positioning within the IS Discipline 7

1.6 Structure of the Thesis 10

1.7 Key Concepts 11

2 Previous Research **13**

2.1 Why So Complex? Exploring Complexity within the Research Context 13

2.2 Model Design of Complex Constructs: Where Hindrances Emerge 15

2.3 Addressing Accessibility: Towards a Holistic Approach? 18

3 Theoretical Lens **20**

3.1 Complex Adaptive Systems (CAS) 20

3.2 Participatory Modeling (PM) 23

3.3 Accessibility in Regional Planning: Theoretical Foundations and Implications 24

3.3.1 Defining and Evaluating Accessibility 24

3.3.2 Regional Accessibility and Agglomeration 26

4 Methodology **29**

4.1 Simulation Modeling as a Method 29

4.1.1 Simulation as a Digital Practice 29
4.1.2 Agent-Based Simulation Modeling 30
4.1.3 The “IT” Artifact 31
4.1.4 Why another model? 32
4.2 Philosophical Standpoint 33
4.2.1 Ontology, Epistemology, and Methodology 33
4.2.2 The Methodological Approach of Simulation Modeling 36
4.3 Research Design and Material 39
4.3.1 Materials, Methods and Data Collection 39
4.4 Ethical Considerations 46
5 Results 48
5.1 Short Summary of Key Results 48
5.2 Results from the Included Papers 51
5.2.1 Paper I 51
5.2.2 Paper II 53
5.2.3 Paper III 55
5.2.4 Paper IV 57
6 Discussion and Contributions 63
6.1 The Complexity Perspective: Model Design for Knowledge Generation 63
6.2 Unpacking Complex Concepts to Reduce Resistance to Modeling 64
6.3 The Regional Planning Perspective 66
6.4 Handling Limitations 69
6.5 Future Research 72
7 Concluding Remarks 75
Bibliography 77

List of Figures

Figure 1: Scientific Positioning 10
Figure 2: Development and structure of the included papers.....40
Figure 3: Structure of accessibility measures 52
Figure 4: Visualization of the research framework for unpacking complex concepts.57
Figure 5: Prevail of preferential visits to larger destination clusters 60
Figure 6: Four-cluster spatial distribution scheme.....61
Figure 7: Potential shortcomings of the complex concept unpacking framework.....73

List of Tables

Table 1. Outline of the research design of the included papers.....41
Table 2. Summary of Key Results of the Included Papers.....49
Table 3. Summary of primary themes and sub-themes 54
Table 4. Main design concepts for the agent-based model of accessibility within a region 59

Keywords

Accessibility, Regional Planning, Simulation Modeling, Sparsely Populated Regions.

Abstract

Simulation modeling has long been used to analyze complicated systems by simplifying real-world processes. These models support knowledge-based decision-making, especially when dealing with imprecise concepts and complex problems. This thesis explores how modeling can improve understanding of complex social processes through the insights generated at the model design of modeling. It focuses on the Swedish case of accessibility planning for sustainable regional development. The thesis examines how accessibility is affected by a lack of institutional cooperation and conflicting definitions. The research adopts the perspective of complex adaptive systems and participatory modeling in several steps covered by the included papers and a discussion concerning the implications of their collective results. First, it investigates the current challenges in planning for accessibility in sparsely populated regional areas as a case study problem, reviewing the methods of accessibility evaluation, its peculiarities in a regional context, and develops the requirements towards a system/tool that answers these requirements. Second, it engages the stakeholders represented by planners and decision-makers from the municipalities within the region to define the basis for developing a model of the mentioned system based on their expert insights into the regional accessibility context – its concept, goals, and challenges. Third, based on the gained insights about the disagreement and ambiguity in defining and deploying the accessibility concept, it develops a research framework that enables to unpack complex concepts such as regional accessibility into more understandable and interpretable associations, engaging stakeholders in the definition process, and consequently, model design based on this process. Fourth, it designs and implements a regional accessibility model, exploring the insights gained from model design process, simulation dynamics, and simulation results to create a cross-municipal vision for accessibility planning through understanding and interpreting its complexity. The framework developed and adopted for this purpose unpacks complex concepts into key modeling variables for the development of conceptual and implemented models, including dynamic simulation models.

Summary in Swedish

Simuleringsmodellering har länge använts för att analysera komplicerade system genom att förenkla verkliga processer. Dessa modeller stödjer kunskapsbaserat beslutsfattande, särskilt vid hantering av oklara koncept och komplexa problem. Denna avhandling fokuserar på det svenska fallet av tillgänglighetsplanering för hållbar regional utveckling. Avhandlingen undersöker hur tillgänglighet påverkas av bristande institutionellt samarbete och motstridiga definitioner. Forskningen antar perspektivet av komplexa adaptiva system och deltagarbaserad modellering i flera steg som täcks av de inkluderade artiklarna och diskussionen kring deras samlade resultat. Först undersöks de aktuella utmaningarna i planeringen för tillgänglighet i glest befolkade regionala områden som en fallstudie, där nuvarande metoder för tillgänglighetsbedömning, dess särdrag i regionala sammanhang, samt utvecklas krav på ett system/verktyg som uppfyller dessa krav. För det andra engageras intressenter representerade av planerare och beslutsfattare från regionens kommuner för att definiera grunden för utvecklingen av en modell för det nämnda systemet baserat på deras expertinsikter i det regionala tillgänglighetssammanhanget – dess koncept, mål och utmaningar. För det tredje baserat på de insikter som erhållits om oenigheten och tvetydigheten i att definiera och tillämpa tillgänglighets begreppet, ett forskningsramverk utvecklas. Ramverket möjliggör en uppdelning av komplexa begrepp som regional tillgänglighet till mer förståeliga och tolkbara samband, vilket engagerar intressenter i definitionsprocessen och därmed utformningen av modeller baserade på denna process. För det fjärde utformas och implementeras en regional tillgänglighetsmodell, där insikter från modellens designprocess, simuleringsdynamik och simuleringsresultat undersöks för att skapa en kommunöverskridande vision för tillgänglighetsplanering genom en förståelse och tolkning av dess komplexitet. Det ramverk som utvecklas och tillämpas för detta syfte bryter ner komplexa koncept till nyckel modelleringsvariabler för skapande av konceptuella och implementerade modeller, inklusive dynamiska simuleringsmodeller.

List of Included Papers

I. Kazieva, V., Große, C., Larsson, A. (2023). Accessibility measures and indicators: A basis for dynamic simulations to improve regional planning. In I. Czarnowski, R. J. Howlett, & L. C. Jain (Eds.), *Intelligent Decision Technologies*, 352, 25–34. Springer Nature. https://doi.org/10.1007/978-981-99-2969-6_3 ***(Conference paper – published, Awarded Best Paper of the IDT Conference)***

II. Kazieva, V., Große, C., Larsson, A. (2024). Accessibility in sparsely populated remote areas: Key variables for informed regional planning. In K. Gao, Y. Bie, R. J. Howlett, & L. C. Jain (Eds.), *Smart Transportation Systems 2024*, 407, 25–35. Springer Nature. https://doi.org/10.1007/978-981-97-6748-9_3 ***(Conference paper – published)***

III. Kazieva, V. (2024). Unpacking complex concepts to enhance use of dynamic simulations. In *The Proceedings of the 28th International Conference on Knowledge-Based and Intelligent Information & Engineering Systems, KES 2024* (pp. 2933–2942). *Procedia Computer Science, 246*. https://doi.org/10.1016/j.procs.2024.09.377 ***(Conference paper – published)***

IV. Kazieva, V., Große, C., Larsson, A. (2024). Towards a Unified Regional Vision: Simulation to Foster Cross-Municipal Cooperation and Planning. *Insights into Regional Development* ***(Journal article – in press)***

Introduction

1.1 Motivation

For an extended period, sparsely populated areas and remote regions worldwide have been experiencing a continuous population decline (Hollander, 2018). This tendency poses challenges even in urbanized areas, as a reduced population in one locale inevitably increases demands in densely inhabited areas. The latter, however, are not designed to accommodate the constantly escalating requirements for demographic expansion.

In response to this crisis, in recent years there has been a transition towards a new paradigm of long-term sustainable planning in regional development (Larsson et al., 2022). Central to the notion of sustainability is the accessibility concept, which refers to the effectiveness of a transport system and can be described as "the physical access to goods, services, and destinations" (Saif et al., 2019). Accessibility has particular significance in sparsely populated areas since the latter exhibit limitations in terms of infrastructure in contrast to their urban counterparts. In the context of this thesis, the accessibility term should not be confused with the one often associated with Information System (IS) research, which explores access to information and is often associated with physical and communication barriers for people with disabilities (Teixeira et al., 2024).

While such regional areas face common challenges regarding the need for development, studies indicate that a region's attractiveness positively influences its development (Zykiene et al., 2021). Consequently, regions seek ways to enhance their appeal to attract population and business or at least halt the negative trend of population decline. It is therefore imperative to define the aspects that can make a region attractive to diverse stakeholders.

Despite the urgent call for active policy measures from decision-makers to address these challenges, development planning in these areas fails to account for the specific needs of regional areas. However, regions experience limited infrastructure and resources combined with longer distances (as opposed to their urban counterparts) between opportunities, leading to

restricted investments in development. Consequently, regions suffer a higher impact from conducted policies than densely populated areas. Nevertheless, in many cases planning approaches for regions are directly applied from experiences gained from urbanized ones as the latter perspective has become the dominating area of interest (Zachrisson et al., 2021).

As the demographic decline in regional areas is already a growing tendency (Grundel & Magnusson, 2022), there is an urgent need to reinforce these areas, which requires knowledge about what is considered attractive for the population and investment opportunities. Thus, accessibility as one of the components of quality of life that contributes to regional development needs to be explored. Since research regarding accessibility is often performed from a certain perspective, (e.g., economic investments, business development), it often lacks a wider holistic view of what opportunities are important for regional development that would make a region attractive to settle in. As a result, even positive effects of increased accessibility may not show advantages of conducted policies immediately which may be misinterpreted as the absence of such. Thus, there is a need to adhere to a comprehensive approach that would include multiple aspects that contribute to accessibility, its evaluation, and planning in the praxis of regional context.

1.2 Why the Sundsvall's Region?

In the settings of these challenges, Sundsvall's region was selected as a representative case study area. The region is a conglomerate of six adjacent municipalities that can be characterized as sparsely populated remote areas with varying levels of urbanization. On one side, the relatively low population density of the area as compared to other more urbanized areas in Sweden and its geographical position in the northern part of the country mark the region as a periphery given its opposition to the modern, economically progressive south (Sjöberg, 2023). On the other side, as the central local municipality is one of the largest ones in northern Sweden, it poses its less urbanized intra-regional neighbors in a position where the latter exhibit traits of rurality as distances between destinations become longer (Paper I). Here,

the rurality is brought up as an opposition to a densely populated area, which, surpassing the urban-rural discussions, evokes a certain image in a reader's mind (Wiggins & Proctor, 2001). Defining an area as rural requires careful consideration of what constitutes the countryside and rurality, as rural areas are diverse and complex on many levels (Gallent & Gkartzios, 2019). Thus, in the context of this thesis, I restrain discussion about the region's rurality as there is no clarity on what specifically constitutes an urban or a rural area.

In Sweden municipalities play a special role in spatial exploration and research as they are the smallest administrative units with decision-making power over area development and growth, making them the key components of understanding regional development patterns. By the geographic classification of Swedish municipalities by the Swedish Association of Local Authorities and Regions (SALAR, 2023) the central municipality of the region is qualified as a medium-sized town, while the rest of the region's municipalities are defined as small cities and rural municipalities. Since the population size and closeness of rurality to its local urbanized center (the latter according to Lavesson (2017) plays a role in the image of a region as urban centers seem to impact their countryside) have not been included in this categorization, the choice of the case study region allows to explore the possible effects of these factors.

1.3 Evolution of Problem Formulation

At the beginning of my research journey, the numerous challenges that the case study faced seemed to pose one problem – how to "solve" accessibility? However, as I delved deeper into the context of the problem, the prerequisites of the specific simulation modeling methodology started to take shape as a good fit that can handle complex systems. This brought along another significant challenge: despite the robust capabilities, simulation modeling faced distrust and resistance from decision-makers. Even models with extensive data support, experienced resistance to acceptance because planners often disagreed on the model's objectives and tasks (Rojas et al., 2022). This hindered the adoption of the methodology and created distrust in

the results even when the issue was not related to method credibility. This challenge is not necessarily confined to different research contexts. Still, it may often be the result of a lack of cognitive capabilities of model users – as (simulation) modeling frequently produces counterintuitive results that are demanding for human nature with its tendency to focus on what is "readily available, salient and concrete" (Sterman, 2000). Another challenge was a lack of a understanding of the methodology and model interpretation, which also applies to the planning approaches in Sweden (Adolphson & Jonsson, 2020). Simultaneously, by communicating with practitioners and studying the literature, I discovered that the practice of addressing and planning for regional accessibility was fraught with ambiguities in approach, definition, and evaluation. The complexity of accessibility definition and evaluation caused challenges in adhering to a common concept[1] and finding a unified approach to its application in praxis (Ryan & Martens, 2023).

While European initiatives stress the need for national and regional cooperation, Sweden's lack of institutional approaches seriously hinders sustainable long-term planning (Bergkvist Andersson & Schmitt, 2024). Here, the view on sustainability comes from the context of long-term regional planning from the official government report developed by the Swedish Housing Planning Committee for increased coordination and improved housing provision (SOU, 2015). The report reviewed and proposed regulatory changes for regional planning to ensure sufficient housing supply and sustainable development nationwide. Long-term sustainable planning was posed as an essential perspective for the Swedish municipalities and regional actors engaged in urban planning, and it covered all three aspects of sustainability: economic, social, and environmental. The document advocated

[1] The latest report of the Swedish Transport Administration elaborates on the definition variations that research and application of the concept experienced during the last 70 years, highlighting that each definition emphasizes different aspects of the accessibility concept (Sandberg & Petersen, 2024). For the sake of the definition breadth, and to include the four measures defining the concept (more about the measures and definitions are given in Paper I), the authors defined the concept as "the opportunities to participate in societal life by overcoming obstacles" (translated from Swedish) e.g., a distance barrier. Yet, since the focus of this work lies in the practice of the concept application in planning for regional growth and development, I find further discussions and elaborations on its practical application reasonable for this research.

for a sustainable approach from a holistic approach, viewing society as a whole system of interconnected social, cultural, ecological, and economic ecosystems that mutually influence one another.

Sustainable vision on planning is specifically sensitive for regional areas, as their opportunities for investments and infrastructure are often restricted, and identifying high-priority needs is crucial for their well-being. However, segregated municipal strategies are not aligned with those of a broader regional perspective as municipalities in Sweden are authorized to conduct their own planning (ibid.). This approach has two-fold implications of risk on regional development in the country: on one hand, the multifaceted nature of sustainable regional planning and development requires contemporary methods that can handle the complexity of these challenges; on the other hand, the lack of institutional regional framework prevents the advantages of collaborative approaches to assist municipalities regions consist of.

This posed new questions – even if we progress in "solving" accessibility, what would this give, and what would be the "solving" part here? The diffusive nature of the problem statement pushed me to detach from the width of this ambition as the case study was fraught with more dimensions of challenges, and one of them was in the basis of its foundation – the lack of a consensus about what we are planning for. Questions remained about the common vision of regional planning that the accessibility concept was embedded in. This entailed challenges about whether the artifact (here: a model of accessibility) was the only "missing" part of the problem, whether there have been the prerequisites for defining what accessibility was as a concept and how it was used in praxis, and what were the peculiarities (distinctive characteristics) and needs of the areas that an artifact would represent. There were several potential entry points.

Considering the above, the research adopted a complex systems perspective since the latter ensured a holistic view on understanding and addressing complex problems like regional accessibility. The complex systems perspective allows viewing these challenges considering the problem in its entirety. What such entirety entails is approaching it as a

dynamic system with several interacting components, where changes in one area can have unforeseen consequences for the entire system. Traditional approaches often overlook these interdependencies, leading to overly simplistic solutions. Framing regional accessibility as a complex problem allows simulation modeling to reveal patterns and non-linear dynamics that are essential for gaining deeper insights into the explored system/phenomenon and its processes. This approach not only improves our understanding of such challenges leading to more meaningful insights and informed solutions to complex societal issues but illustrates the consequences of certain decisions, such as outcomes of the regional planning approach.

Among simulation modeling approaches, restricting the thesis to using agent-based modeling (ABM) is justified due to its capacity to handle complex problems, as the method simulates individual behaviors that reflect social context at a micro level. This enables a model designer to examine how such interactions give rise to patterns emerging at a macro level. This implies that ABM is well-suited for exploring the individual influences on the dynamics of the explored system/phenomenon for studying complex systems. The methodology chapter includes more details on choosing ABM as a method.

Therefore, instead of jumping into developing another extensive data-driven model that might still face rejection and not serve the distinctive purpose, the research was reoriented to address the underlying lack of consensus regarding the concept of accessibility. This means that a common vision of a problem and a shared understanding of the concept definition and application are addressed before building up a detailed reflection of the accessibility system. At the same time, as the resistance towards modeling, often seems to stem from insufficient communication and interpretation of the assumptions and underpinnings of simulation models (Kayande et al., 2009), I decided to expand the focus. Finally, the scope of the research was adjusted to synthesize both sides of the medal: achieving the common vision in contemporary challenges posed by the accessibility part of sustainable regional development and the interpretability of simulation modeling in the settings of complex system domains, such as the embedded concept of regional accessibility in the case of this thesis.

1.4 Objective and Research Questions

The objective of this thesis is to investigate how simulation modeling can effectively address the complexity involved in evaluating accessibility in regional planning practices and assess how a complex systems perspective can help integrate simulation modeling into decision-making processes for sustainable regional development. The goal is to explore the capabilities of simulation modeling[2] to enhance the understanding and interpretability of complex problems/concepts. In this thesis complex concepts refer to concepts that complex systems address (introduced in Paper III). More specifically, when referring to the complexity of such concepts, a reader bears in mind a problem that lacks a clear definition, goal, or means of moving toward this goal (Dörner & Funke, 2017). In this thesis, regional accessibility is the showcase of what I refer to as a complex concept, that currently suffers from the lack of consensus and common theoretical and methodological grounds of dealing with it. Thus, this thesis addresses the following research questions:

RQ 1) How can the complexity of accessibility and its evaluation be addressed in sustainable regional planning?

RQ 2) How can the perspective of complex systems and concepts facilitate the adoption of simulation modeling as a digital practice in decision-making

1.5 Positioning within the IS Discipline

In Scandinavia, the academic tradition of the Information Systems (IS) subject, also referred to as "informatics", has witnessed the evolution of the field from almost pure data processing in the early 1960s to contemporary information systems with information and technology in focus. The rapid advance of

[2] While simulation and simulation modeling are often used interchangeably, there is a subtle difference between the two notions. Simulation modeling is a step in a simulation study, where the latter involves modeling, analysis and presentation (Kin & Chan, 2011). Simulation modeling uses expert knowledge to create a simulation model, that replicates a real-world process or phenomenon. Such model can be applied in simulation to provide understanding of the system of interest (Niloofar et al., 2021). Thereof, simulation modeling highlights the *process* of developing a simulation model, while simulation refers to replicating or running the model.

industrial and technological developments led to the widespread digitization of society, inevitably affecting the IS field as well.

The current definition of the subject, updated in 2020 by the Swedish Information Systems Academy (SISA) defines the IS in Scandinavia as a scientific subject that develops knowledge about digitalization and its pre-requisites, meanings, values, and consequences in individual, organizational, and social contexts. By revisiting the definition that in 2015 revived around human design and IT application, the new IS definition introduces digitalization and its practices as the major development direction of the Scandinavian IS. This change reinforced the need for developing digital practices, artifacts, and systems, defining the scope of digital practices to cover the research of the governance, design, implementation, and use of these digital resources, artifacts, and systems. Consequently, the core of the discipline was rooted in the technological part of the IS with digital technique in focus. As of today, the IS scope spans multiple fields that apply information and communication technologies, placing IS research on the shoulders of cross-disciplinary challenges confronting society and technology.

As one of the main directions of IS entails digital practices, this thesis uses the advantage of simulation modeling as a digital method to generate knowledge that can enhance the application of digital practices to support regional planning and decision-making (DM). The idea lies in using simulation modeling as a method to learn about a complex phenomenon by exploring the dynamics and emergent behavior of the model that represents the complex system in question. In this thesis, the system covers the concept of regional accessibility. The exploration is done via simulation modeling that consolidates research of several studies as per the included papers.

Thereby, the digital artifact – the model – enhances planning via the adoption of digital practices to inform DM with insights through the learning capabilities of simulation modeling, i.e., with information about the phenomenon in question. By supporting DM with digital practices, the study aims at reducing the resistance towards modeling as a method, exploring the advantage of the model design stage in generating insights into the problem,

and bridging the gap between theory and modeling. This way digital practices are brought closer to practitioners who become a part of developing the digital artifact. For IS, the research advances model development [3] by providing a concrete approach to extracting and operationalizing key variables from theoretical concepts within complex system domains. Unlike previous research, which provided general guidelines for transitioning from theory to modeling, this approach creates concrete steps for approaching model development. This way of connecting theory and simulation modeling brings the spotlight on model design stage capabilities as opposed to solely relying on the results generated by simulations.

To assist DM which deals with the problem of understanding complex problems and designing policies for them, the thesis employs ABM to contribute new insights into handling regional accessibility as a case study of complex problems. The challenge is that despite the availability of digital practices that can support DM with insights into the problem, the advantage of the illustrative and learning capabilities of simulation as one of such practices is largely neglected. This thesis uses simulation modeling as a tool for learning, advocating for its applicability at the level of policy design for informed DM when policymakers need support that can handle contemporary challenges. Figure 1 summarizes the position of this thesis in the areas that this work engages to answer the research questions. The methodological approach chapter details the position of the thesis concerning the IS as it explores it from the digital practice point of view, elaborating on its methodological aspects. At the same time, the theory chapter of this thesis elaborates on the theoretical underpinnings that Figure 1 presents in the righthand side; the lefthand side exhibits the main contribution to the IS area

[3] In this thesis, model design or model development is seen as a stage in the simulation modeling process between conceptualization and model implementation. In the modeling cycle of ABM as presented by Railsback and Grimm (2019), model design would best fit between the Assemble Hypotheses and Choose Model Structure steps.

(the research framework for developing variables for modeling), and the main method of the thesis that ties the disciplines.

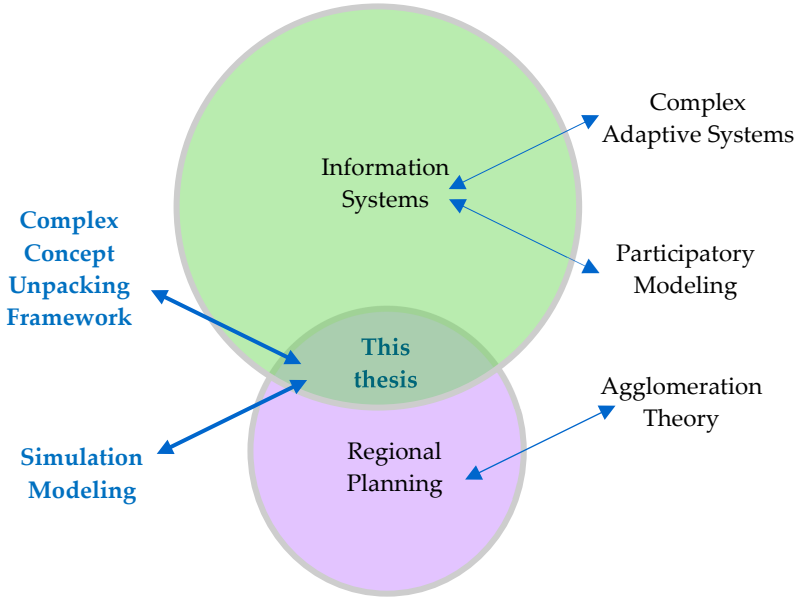

Figure 1: Scientific Positioning

1.6 Structure of the Thesis

This thesis is structured as a compilation work of the four included papers and their summary (the present document). The latter extends the ideas and findings of the papers based on the objective and the research questions stated in this chapter discussing and concluding the whole research. The disposition of the thesis is as follows:

- Chapter 1 introduces the context of the research, problem, subject area, and position within the IS discipline, as well as the motivation, objective, and research questions of the thesis.
- Chapter 2 covers previous research related to the research context.
- Chapter 3 explores the theoretical lens of the thesis.

- Chapter 4 covers methodological underpinnings including the review of simulation modeling, a philosophical standpoint, expands the scientific position of the thesis from the methodological point of view, presents the methodological approaches of the thesis and its included papers, and elaborates on ethical considerations.
- Chapter 5 presents the results of the research.
- Chapter 6 discusses the research results, contributions, limitations, and future research.
- Chapter 7 draws on the concluding remarks.

1.7 Key Concepts

A **system** describes real-world processes or phenomena of interest that can be studied scientifically through a set of assumptions about how such a system works. Given the complex system approach of the thesis, the most appropriate description of a system for this thesis would be "a representation of an entity as a complex whole open to feedback from its environment" (Ryan, 2008).

A **complex system** is "an ensemble of many elements interacting in a disordered way, resulting in robust organization and memory" (Ladyman et al., 2013). The complexity usually lies in the number of parameters or interacting parts of such systems, that can be complicated to represent or describe. An example of such a complex system is a community.

A **complex adaptive system** (CAS) – is a system that combines multiple elements that interact with each other and their environment and adapt (react) to these interactions and changes in the system (Holland, 2006).

An **agent** describes an element of a complex adaptive system. In agent-based modeling (ABM) agents refer to individuals or organizations of the real world and depict the behaviors and (inter)actions of these real-world actors (Held et al., 2014).

A **model** can be described as an abstracted representation of a process, object, or event (Wilensky & Rand, 2015). It represents a formation of a set of

assumptions expressed through mathematical or logical relationships. In the context of this thesis, a model denotes a non-physical model of a complex real-world phenomenon explored as a system "composed of many distributed interacting parts" (ibid.).

A **simulation model** represents a real-world system in a simplified form of a computer program with fewer details than the original system (Gilbert & Troitzsch, 2015), yet enough to be considered as a reflexive representation of the original one. Its goal can be to try to understand some specific social phenomena (or a process), e.g., how a certain opinion starts to prevail in a group of people.

A **complex problem**, or a problem in a complex system's domain, defies a problem that lacks a clear definition, goal, and means of moving toward the goal (Dörner & Funke, 2017).

Accessibility is described in scientific literature as "the ease of access to activities, facilities, and locations" (Jamei et. al, 2022), i.e., physical access to various opportunities (destinations). In the context of this thesis, I often refer to regional accessibility as the case study of the region of Sundsvall. This region unites six municipalities - Sundsvall, Timrå, Härnosand, Ånge, Hudiksvall, and Nordanstig. This region is not a formal geographical formation but is formatted from a collaboration between the mentioned adjacent municipalities that exhibit similar characteristics of remote sparsely population regional areas with varying levels of urbanization (later on these areas are shortly referred to as regional areas or simply regions).

2 Previous Research

2.1 Why So Complex? Exploring Complexity within the Research Context

As the European Commission stressed the need to explore way of empowering regional development (European Commission, 2015), the municipalities within Sundsvall's region created a collaboration[4] to study relationships between factors, that affect regional development. One such factor, that this research focuses on, is accessibility, specifically, its influence on regional development that can enhance planning to halt the negative trend of population decline in the case study region and sparsely populated remote areas in Europe that exhibit similar characteristics and challenges.

Accessibility can be described as "the ease of reaching" (Preston & Rajé, 2007) or "the ease of access to activities, facilities, and locations" (Jamei et. al, 2022), i.e., the ease with which an individual can reach a destination, for example, a grocery store. The concept is often used as transport accessibility in literature to distinguish between other types of accessibility, such as physical accessibility for disabled people. I am conscious of describing it as transport accessibility to ensure that it does not mislead readers into thinking that the land-use part of the modern concept of accessibility may be ignored.

While there is no universally accepted way to determine what approach to research is "correct" for a given context, the rationale behind the selection of such can vary based on numerous factors, for example, the initial problem and knowledge about it. Contemporary research of urban and regional areas treats cities and regions as complex systems (Allen, 1995; Rybski & González, 2022) that consist of adaptive self-organizing subsystems interacting on multiple levels – economic, demographic, and environmental. However,

[4] The project "Perspective on Accessibility" was initiated to examine the relationships between the transportation system, infrastructure and regional development. This collaboration united researchers and municipal workers engaged in various level of decision-making to enhance the understanding of diverse perspectives on accessibility within the context and the factors that can contribute to the creation of the appropriate level of accessibility in sparsely populated areas such as the Sundsvall region.

when dealing with complexity, the questions arise: aren't most things around us complex in a certain way? And how do we then define what perspectives on complexity should be included?

Estrada (2023) extracted several key factors that build up complexity - characteristics of interacting elements with a large number of parameters, nonlinearity, and emergence (self-organization). To avoid abandoning meaningful discussions about the concept definition, I highlight the concept that I find the most relevant for this research. It defines a complex system as "an ensemble of many elements which are interacting in a disordered way, resulting in robust organization and memory" (Ladyman et al., 2013). This description is in tune with modeling that tries to capture an image of a real-life system and an image of a region that in the context of this research consists of several municipalities with similar characteristics in terms of levels of urbanization and remote distance from large cities. Given that this case study addresses the challenges of sparsely populated remote areas, it is important to keep these areas in mind throughout this work when referring to "region(s)" or "regional area(s)." It is here, in the settings of the complex adaptive characteristics of regions, that the capabilities of simulation modeling of dynamic systems shine through due to its potential to enhance the understanding of the entangled design of urban and regional realms (Kelly et al., 2013). The capabilities of modeling can enhance this understanding not only by exploring the behavior of a region via a model but also by designing it and engaging its stakeholders in the modeling process. The argument for this statement lies in the *process of model development* (I often refer to it as model design throughout the narration), which is even more valuable than the simulation results themselves since developing a model shows the potential to significantly enhance the understanding of complex (social) processes of a research area (Gilbert et al., 2018). Reflecting on the objective of this thesis, this potential of model development can be used to explore the challenge of interpreting the complexity of a phenomenon (as a general case of complex systems research within IS), and, to the special case of regional accessibility (as the application area of IS).

2.2 Model Design of Complex Constructs: Where Hindrances Emerge

Simulation modeling includes both model development and the experimental parts where the model is applied to study a real-life system (Shannon, 1998). One of the earliest models of social phenomena developed back in 1969 by Thomas Schelling (Hegselmann, 2012) explored the complexity of forming residential segregation was implemented with a checkerboard and pennies. These two "types of agents" as ABM [5] would describe them nowadays reflected the dynamics of different races (pennies) moving from one residential cluster (several pennies residing on the squares of the board) to another. The movement depended on how many residents of the opposite race in the current cluster each race was "willing" to settle with. This highly abstract, yet simply constructed model simulated the patterns or dynamics of a complex societal system formed from individual preferences. Since then, several different types of simulations of non-physical systems have been developed, rendering these basic characteristics of simulation modeling such as adaptive behavior (in Schelling's model the adaptive behavior would comprise each resident's decision-making depending on the similarity content of its neighborhood) and the emergence of patterns (in Schelling's model it would be the population clusters that after many choices become highly saturated with pennies of the same "race", signaling for high levels of segregation) to be unparalleled, far surpassing its analytical, statistical, and mathematical counterparts.

Despite these advantages and the obviously non-mystical nature of processes underlying simulation modeling, Grimm et al. (2006) highlighted that the adoption of such models in practice is rife with resistance from the decision-makers, who distrust the method. Simulation is deemed as a mystic method often due to its emergent properties. The emergence of patterns is otherwise unavailable through traditional methods – as in the example of Schelling's model, the mystical part would be the formation of highly

[5] A type of dynamic simulation modeling based on interaction of separate elements, called agents. More about this type of simulation is discussed in the methodology chapter.

segregated clusters with the same races. However, by breaking down the essence of this method into separate constituent steps, one sees simple processes that comprise moving from one cluster to another, evaluating the tolerance in the new cluster, comparing it to own tolerance, deciding to move if the tolerance is lower, performing the move, causing other people in the cluster to do the same evaluation. The combination of these simple steps finally leads to what is known as emergent patterns or dynamics of the simulated system (of race segregation) as one observes a highly segregated society. This feature of simulation is what often creates distrust in the credibility of simulation modeling due to the seemingly mysterious nature of the emergent results.

To address this hindrance and distrust expressed by the scientific and decision-making societies towards simulation modeling, and to assert the role of ABM as a rigid methodology that supports credibility, reproducibility, and replicability of research, scientists (ibid.) developed a comprehensive ODD (Overview, Design concepts, Details) protocol. The protocol serves as a standard for describing ABM models regardless of the research field. The advantage and goal of it lies in the necessity to thoroughly define the purpose, process, and design concepts as well as conceptual and implementation details of the model. This allows other researchers in the field to reproduce and expand the model from this description, supporting the transparency and reproducibility of the research methodology. Even though scientific society willingly accepted this standardization due to the open and established approach of developing the protocol, the practice of deploying ABM and simulation modeling as such is still experiencing resistance and criticism (Lawlor & McGirr, 2017). To adhere to these demands, model designers resorted to the issues of verification and validation to reassert the rigor of the research performed through simulation studies. Wilensky and Rand (2015) elaborate on the aspects of model accuracy by describing validation as a process that establishes the correspondence of the implemented model to the real-life system or phenomenon that the model embodies, while verification defines whether the implementation accurately reflects the conceptual model that describes the system in question.

To support the credibility of ABM, Rand and Rust (2011) elaborated guidelines to ensure the analysis that ABM models provide as a research methodology answers the demands for model credibility. Their work covers a checklist of evaluating the pros and cons of applying a specific method for the given research, elaborating on other close methods that could be a potential alternative match when ABM does not demonstrate a strong advantage. Their research even covers several general steps that are directly related to model development: together with decision whether ABM is the appropriate methodology, designing the model, constructing the model, and analyzing the model. To provide an example of what aspects such steps cover, one of the last steps covers running the simulation and using different techniques for interpreting output. This way, the model development guide given in their approach covers the aspects of *what* must be included in a model, which elements, interactions, and behavior rules should be designed and described without elaborating on *how* such choices should be made. The guides are in tune with major ABM principles and are included in the mentioned ODD protocol.

In light of these improvements towards the rigor of the methodology, modelers diverted their focus from addressing distrust ascribed to the pitfalls of the methodology, towards the relations with the stakeholders of the models, as in many cases their resistance was caused by a disagreement about assumptions and underlying factors of simulation models (Kayande et al., 2009; Belfrage et al., 2022). This shift gave rise to the formation of participatory modeling where model developers collaborate with stakeholders (e.g., decision-makers) during different steps related to model development to ensure that the stakeholders are engaged in the process and contribute their expert knowledge. Quimby and Beresford (2023) argue that the approach is specifically critical in social science research which is built on the vast majority of (often imprecise) data that requires a series of assumptions, interpretations, and concept agreements. The authors generalize their views on the forms of participation into different stages of the modeling process: selecting roles and sites, identifying and recruiting participants, formulating the model, conceptualizing and building the model, validating the model, as well as analyzing data throughout the last three stages. The research does not cover

in detail the approaches or methodologies of the steps, such as model design or *how* agreement on defining the goal of the model is reached. Instead, it equips modelers with a variety of approaches that allow cooperation between the stakeholders and model designers. An example of what such approaches cover is a model formulation stage where the authors suggest tools like interviews, surveys, and focus groups to define the scope of the questions that the model is expected to address.

This identification of cooperation possibilities concerning the hindrance to adopting simulation modeling as a credible methodology underscores the need for further research into more concrete steps, specific techniques, or frameworks to suggest *how* the interpretation of a complex system or concept can be done. Such advancements could support participatory modeling in countering the modeling resistance trend and improve the interpretability of the problems and concepts addressed within the complex system domains.

2.3 Addressing Accessibility: Towards a Holistic Approach?

The idea of using simulation and modeling capabilities to address complex problems of urban and regional planning is not novel. Related studies often evaluate accessibility using accessibility indicators (Buzási & Csete, 2015), which are defined as a descriptive measure of spatial structure and performance (Morris et al., 1979). At the same time, such representation through segregated indicators is insufficient to capture the emergent properties of a complex self-organizing system (Paper I). Other studies explore limited contexts (such as land suitability by Burian et al., 2018), policies (e.g., Gorecki et al., 2023), or specific transportation modes (e.g., railway by Rotoli et al., 2015). López et al. (2018) emphasize the need for a holistic approach to halting the problem of population decline, arguing that understanding the dynamics of the accessibility system can assist decision-makers in seeing the bigger picture that segregated approaches overlook.

One of the previous studies suggests a diverse model of the integrated dynamic land use and transport interaction (LUTI) model MARS (Metropolitan Activity Relocation Simulator) (Pfaffenbichler et al., 2008). It deploys System Dynamics (SD) methodology to simulate travel behavior by integrating the following submodels: a housing development model, a household location choice model, a workplace development model, a workplace location choice model, as well as a fuel consumption and emission model. SD is used to define the cause-effect relations that pinpoint the factors that influence different activities (e.g., taking a car to travel from one zone to another). The model is deterministic and is based on the real-world data accumulated specifically for simulating the activities in separate areas of a city, i.e., it functions at medium to low levels of model abstraction. This level of abstraction is characterized by concrete goals and a high level of detail as compared to highly abstract models (Borshchev, 2013).

One of the latest empirical studies that looked into accessibility implementation challenges (Ryan & Martens, 2023) revealed a discouraging perspective of the Swedish context substantiated by interviews with practitioners from other regions (in Belgium and the UK). It showed that authorities are not only hesitant to develop a common approach to address and evaluate accessibility, but they also disagree on how to define the very concept itself.

Considering the foregoing, a reasonable way forward would be to explore how practitioners understand and use the concept in praxis, and to integrate their insights and underlying perspectives in model design.

3 Theoretical Lens

In their work "Simulation for the Social Scientist," Gilbert and Troitzsch (2015) define the role of theory as a guide that includes elements and dynamics and asserts that a model accurately reflects the real-world phenomena under study, connecting it to established research. For a model designer, theory serves as the critical basis that shapes the design process and assists in the identification of key model features as well as the dynamics or interactions that need to be represented. Given the problem statement of this thesis, the theoretical underpinnings will inform the study through the concept of complexity and its representation in a (dynamic simulation) model design.

3.1 Complex Adaptive Systems (CAS)

Throughout my research journey, the frameworks that I considered first were complex systems theory and general systems theory (GST). Both approaches enable the exploration of behavior of a system as an interconnected organism with multiple components that give rise to unpredicted and often counter-intuitive patterns. At the same time, as the problem of the thesis started to take shape, exposing the lack of a common understanding of the complex concept in question, I had to dig deeper into the possible underpinnings of the problem of the complex concept interpretability. Consequently, the theoretical lens of CAS emerged as a special case of GST. To avoid adding messiness to the debates around the scope and overlap between the two approaches (Turner & Baker, 2019), I adhere to the main characteristics that define CAS as: “inter-relationship, inter-action, and inter-connectivity of elements within a system” (deMattos et al., 2012).

Central for CAS is its self-organizing quality, which means that the system elements react to external stimuli, changing their states to adapt to the new environment. The patterns or dynamics of such self-organization lead to what is known as emergence – a rise of relatively complex, often unpredictable, and non-linear dynamics and patterns of the system and its

agents (Railsback & Grimm, 2019). An example of emergent behavior is the formation of the crystalline structure of snowflakes.

One of the core principles CAS involves studying the system in its entirety. This approach emphasizes the importance of addressing the behavior and dynamics of the system as one organism while simultaneously examining its constituent elements in relation to one another and to the system as a whole (Holland, 2006). Even though this idea is best adopted in ABM where both the system and its decomposition into agents contribute to adding knowledge to the problem under consideration, I find it useful to bring up key aspects of the dynamic simulation method of SD to draw a parallel between CAS and SD's feedback loops that assist learning in the settings of complexity.

Since complex systems do not follow a simple, linear cause-effect manner, it is difficult to predict the outcomes of their behavior using traditional methods. Jay W. Forrester, the father of SD (1971), argued that a system-oriented, closed-loop approach provides a more accurate representation of how actions within a system lead to future challenges and responses. Feedback loops, a core component of SD, allow for continuous learning and adaptation by modeling the cyclical nature of cause and effect within a system. This is particularly important in addressing dynamic complexity, where multiple nonlinear dependencies and side effects, which are often overlooked in conventional analysis, play a significant role.

The idea of feedback loops that gave rise to the simulation methodology of SD originated from the need to explore the cause-and-effect relations between the system elements. However, in complex settings as decision- and policymakers tend to ascribe one consequence to a single reason, the reality of a complex world where changes in one part of a system that may have a ripple effect on another, seemingly unrelated part, do not get considered (Sterman, 2000). Such constellations of feedback loops around different parts of systems amplify or reinforce a certain part of a system thereby supporting the idea of systems thinking, i.e., exploring strong or weak constellations to identify the potential for optimizing the system performance. This approach

is therefore valuable not only for detecting the "high (or low) leverage points" (ibid.) but also for dealing with imprecise concepts that operate at a high level of abstraction and may not be easily evaluated/measured (Paper I). By detecting higher-level system correlations, the feedback loops incorporate "soft" variables, such as interpretations of complex concepts, or other components of a system that may be hard to quantify. According to Forrester (1971), SD allows one to define which loops (positive or negative) dominate the system or its part, thus determining its dynamics, or changes in behavior. Similarly to high points of change in social systems, these insights generate knowledge about the activities, policies, or decisions that are likely to change the course of events in the system. When contemplating the praxis of model adoption in the initial stages of developing the approach, Forrester (1961) argued that when applying models "we should look less for prediction of specific actions in the future and more for enhancing our understanding of the inherent characteristics of the system."

For complex system domains, this approach from the systems thinking point of view could ensure that the impact of system elements will be included in the interpretation of the system development over time for a holistic understanding of the underpinning processes that guide this development (or development of a simulation model over time). Referring to the discussion about the potential of modeling to enhance the interpretability of complex problems through the process of model development (see the "Previous Research" chapter), the argument is that the conjunction of these approaches (insights through model design and the feedback principle) has the potential to amplify the interpretability of a complex system in question.

Further details about the underpinnings of simulation, specifically the main methodology of ABM and rationale for model development are presented in the Methodology chapter of this thesis. Inevitably, given the research context, chapters addressing theoretical and methodological underpinnings share some overlapping discussions, and deciding in which chapter to place parts of these discussions often involves a trade-off.

3.2 Participatory Modeling (PM)

PM is an interdisciplinary approach based on the involvement of stakeholders in the modeling process to enhance decision-making, system understanding, and the legitimacy of the model outcomes. PM can be described as a type of collaborative paradigm, developed in order to engage diverse knowledge from stakeholders' participation (Bartels & Furman, 2023). Kimmich et al. (2019) exemplify that the field of PM has received little attention from the scientific advance compared to its counterparts, such as focus groups or citizen panels, even though in the settings of low consensus, high uncertainty, and need for co-decision, it is significantly resourceful.

PM approach draws on several theoretical foundations, including systems thinking, social learning, and collaborative governance, and is characterized by the inclusive and transparent form of producing knowledge. In their research, Belfrage et al. (2022) explored this type of collaboration with decision-makers to enhance the empirical base of simulation models. Their review provided a unified approach for conducting simulation-based policy collaborations with a focus on the early involvement of policymakers, the collaborative development of a dynamic project plan, and the importance of transparent communication throughout the process. To align the expectations with the responsibilities of the parties and model credibility, as well as to ensure that the collaboration remains responsive to the problem statement, the approach established a set of five recommendations that guide model development:

R1. Modelers can adopt a facilitative role by prioritizing policymaker input during the model design while minimizing their own influence.
R2. Agree on a project plan as early as possible so that expectations are aligned and commitments are made.
R3. Include policymakers early in the project and tailor activities to their needs.
R4. Communicate model capabilities, limitations, and results – comparatively between each model version if possible – in a clear and nuanced way.

R5. While broad stakeholder participation is worth striving for, the collaboration needs to remain quick and agile to maximize its usefulness for policymakers.

To incorporate these recommendations in the praxis and reduce policy resistance, the authors suggest tying these recommendations under a unified framework. Such a framework functions as a flexible environment with clearly defined initial goals, transparency in communicating the preferred collaboration form and expectations, and an agreement on the time, scope, and output of the intermediate activities. Modelers are viewed as technical designers, meaning their participation is limited to the discussion about technical capabilities of realizing the framework/project ideas, with the main role in the framework as the facilitator of the communication. According to the authors, the approach serves the practical purpose of reaching outcomes that will be as practically applicable to the stakeholders (here, the stakeholders refer to the end users of the model, in my case study - decision-makers) as possible, minimizing the risk of resistance to modeling.

3.3 Accessibility in Regional Planning: Theoretical Foundations and Implications

This subchapter delves into the theoretical underpinnings of accessibility, exploring its role in evaluating and shaping regional planning practices.

3.3.1 Defining and Evaluating Accessibility

Accessibility has emerged as a central concept in regional planning, influencing how spaces are designed, connected, and experienced by individuals and communities. The discussion will focus on how accessibility is conceptualized, measured, and operationalized within the planning process, and how these elements are deployed in real-world scenarios. By

understanding these dynamics, we can better appreciate how accessibility informs planning decisions and contributes to the development of regions with access to essential resources, services, and opportunities.

The concept of accessibility was introduced in scientific discussions around urban and transport planning by Hansen (1959), marking the shift from a simple matter of mobility to the "potential of opportunities for interaction" (ibid.). Apart from the two key components – land-use and transportation – the concept includes temporal and individual elements, such as opening hours and personal needs (Lättman et al., 2018). In contemporary rural settings, where key destinations and residences are spread out, a lack of transportation limits opportunities for work, education, recreation, and social interaction, thereby becoming the key enabler (or disabler) of accessibility. The accessibility term itself can be ascribed both to people and places (Geurs & van Wee, 2004) – a destination may have a varying degree of accessibility, and a person may have diverse levels of accessibility to different destinations (e.g., due to personal preferences).

The change of paradigm towards the ease of interaction has posed multiple challenges in defining and evaluating accessibility. Considering that the concept as a part of sustainable development can have implications on multiple aspects of human lives, such as the environment, public health, employment, and social inclusion (Paper I), the inclusion of contemporary approaches that can handle this complexity becomes crucial for effective planning. Despite this change, there is currently no consensus on what accessibility entails, or how it should be evaluated (ibid.). Still, in many cases, accessibility is associated with the provision of connectivity between people and places, which leads to studies treating transportation as an enabler of accessibility (Saif et al., 2019), rendering the concept to exploring the effects of separate transport modes or transport infrastructure.

Methods of accessibility evaluation face similar challenges as its definition does, mainly due to the lack of tools that can handle its complexity and consider the specific context to ensure the intended use of the notion is being adequately incorporated in the evaluation (Lättman et al., 2018).

Evaluation of accessibility is often performed through its indicators which represent a descriptive measure of spatial structure and performance (Morris et al., 1979). The need for adjusting the evaluation to the context may result in selecting overlapping, unrelated indicators, at the same time disregarding the ones that are relevant but hard to measure or operationalize (Geurs & van Wee, 2004), since there is no set of indicators generally applicable to different contexts. An example of such unrelated indicator-based evaluation can be infrastructure measures, which ignore the impacts of land use and spatial distribution of opportunities, challenging analytical approaches of evaluating accessibility with the need to select a measurable, restricted set of indicators and define how to evaluate each indicator (ibid.). The systematic approach that Geurs and van Wee developed in the form of grouping the indicators partially reversed the problem of overlap and laid grounds for including the indicators relevant by their theoretical, operational, and interpretability criteria. This does not exceed the capabilities of what analytical solutions can do for each measure (grouped set of indicators) as their discrete nature fails to capture the contemporary complexity of the notion, such as change in either the dynamics of the accessibility system or in the patterns of interaction. The problem with analytical (and statistical) approaches lies in their restricted capabilities of capturing several parallel interactions, forcing the evaluation to adhere to the assumption of independence (when observations are considered not to influence each other [6]), which rarely is the case in complex systems that incorporate human behavior and multiple actors.

3.3.2 Regional Accessibility and Agglomeration

In Sweden, public administration involves collective decision-making by government, independent authorities, and strong local self-government. Planning at the municipal and regional levels experiences segregated approaches as the scope of institutional cooperation is not strictly governed and varies throughout the country. The Regional System Analysis Method

[6] In this context, the assumption of independence applies to disregard of correlation between variables, events and/or experiments.

(RSAM), introduced to improve regional and national coordination in transport systems through general guidelines, revealed gaps in practical implementation due to a lack of systematic approaches and reliance on experience rather than theoretical frameworks (Adolphson & Jonsson, 2020; Große & Olausson, 2019).

At the same time, planning strategies for regions are often borrowed from urban areas, where agglomeration effects—such as economies of scale, network benefits, and innovation clusters—are well-documented and generally positive (Zachrisson et al., 2021). As the application of urban approaches to regions neglects the unique needs and peculiarities of the latter, the adoption of the urban-focused theories can result in the misallocation of resources, as investments intended to stimulate regional development are instead concentrated in already thriving urbanized areas. Since municipalities develop their own strategies, the segregated planning approach that ignores the cross-municipal visions, especially in regions like Sundsvall, with varying levels of urbanization, may potentially lead to competition among the municipalities. For example, while peripheral regions may experience economic benefits from improved accessibility, these advantages are frequently outweighed by the more significant economic gains observed in central areas of these regions (Kotavaara et al., 2014). This not only widens the gap between more and less urbanized regional areas but also creates a risk for less urbanized areas as the latter may stuck in a perpetual state of underdevelopment. This disregard for competition highlights the need for a more region-tied exploration of agglomeration approach in regional planning, ensuring that micro municipal planning is not causing negative macro regional effects. Instead, planning must acknowledge the possible risks of urban models and segregated approaches in aggravating intra-regional competition in the absence of a common cross-municipal vision. But what does the agglomeration theory entail?

The theory of agglomeration is based on the idea that the benefits of firms and workers increase when the local economy shows growth (Combes & Gobillon, 2015). Agglomeration emphasizes the advantage of physical

proximity by spatial clustering or concentrating economic activities which results in economic growth for industry and promotes knowledge clustering.

The central concept of the theory lies in external economies of scale, that arise when firms not only optimize their internal operations but also benefit from a network of economic activities. This includes access to specialized labor, shared infrastructure, services, and a competitive environment. The benefits from internal economies of scale occur as firms gain from serving large markets, and are therefore not central to the theory, as it excludes the spatial distribution component (McCann & van Oort, 2019).

Typically, a concentration of firms leads to the establishment of institutional structures, innovation, and skill development, which collectively encourage agglomeration. Even though the approach may spur economic growth, it can also have negative consequences, such as increased living expenses. Researchers point out that the extent to which policies strive for agglomeration should not be – the more the better (Ximénez-De-Embún & Sanso, 2011). Instead, DM should consider an optimal level of concentration unless the aim is to create an overpopulated urban monster next to a desolated land, whenever certain cities exhibit somewhat lower levels of urbanization compared to their expanding metropolitans. Studies emphasize that the agglomeration of industry depends on the size of population settlement, and certain manufacturing will experience different effects from clustering. Less urbanized areas may experience the advantages of agglomeration in industry, while more urbanized ones may experience growth of a different scale, such as business establishments or educational institutions (Gill & Goh, 2010). At the same time, research on clustering effects from other types of human-based activities beyond industry and work opportunities is restricted, even though the role of such opportunities in the formation of societal changes effect on the development of an area is often more substantial (Große, 2022). It is therefore crucial to evaluate the potential drawbacks when resorting to clustering to ensure that possible risks are adequately addressed. Paper IV explores the theoretical underpinning of regional accessibility and agglomeration in the planning context of the case study area in more detail.

4 Methodology

4.1 Simulation Modeling as a Method

To understand the reason for adopting simulation and designing a model, I start with a bird's-eye view on simulation modeling and specifically ABM as a digital practice, guiding the reader through the studies (papers) that the research methodology of this thesis comprises.

4.1.1 Simulation as a Digital Practice

Simulation is known as a "technique for using computers to imitate the operations of various kinds of real-world facilities or processes" (Law, 2015). This definition links simulation to the digital practice of computer simulation but diminishes its role as a method (Durán, 2021). It is therefore important to reinforce simulation in its methodological sense as the case study of this thesis deploys the capability of simulation to learn how processes of real-world systems develop over time (ibid.). As the aim of the method is to study what is usually referred to as a system that comprises processes of the real world or facilities (physical environments), certain assumptions and simplifications need to be made in order to reflect the system in question in its digital form of a model (Law, 2015). A simulation model enables the conduct of experiments in a digital format and is designed to serve a specific aim, as in this case, to assist in answering the research questions of this study. However, models do not replicate reality precisely, meaning in all its details (Kin & Chan, 2011). Instead, a researcher modeling a system decides what to include in the model based on the knowledge about the system. These decisions depend greatly on how the model is intended to be used. In quantitative research, the system's characteristics lay the ground for variables of a quantitative design.

A non-physical simulation model can be conceptual or implemented. Conceptual models are descriptive representations of implemented models. They are the first step in modeling serving as a basis for developing an implemented model. Conceptual models can be developed in the form of a

text, a diagram, a block scheme, or a pseudo-code. Implemented models are computer-based digital artifacts developed in a simulation environment based on the conceptual ones.

Dynamic simulations model a system that shows changes over time (Law, 2015). There are three major types of dynamic simulations of non-physical systems – ABM, SD, and discrete event simulations. Among them only ABM and SD are continuous, i.e., they explore systems with variables that can change over time (Law, 2007, pp. 70-76). This is an essential trait to represent a real-world complex system that is subject to changes over time and is specifically important in this study that explores regional accessibility – a complex concept that suffers from a time lag problem and is interesting to study how its dynamic evolves. An example of such dynamic changes could be a decreasing attractiveness of overly visited destinations; another example from a different subject area would be a changing state of patient's contagiousness in a pandemic simulation. A vital and distinctive trait of ABM as a method compared to its counterparts is its capability to represent heterogeneity (divergence) of population agents, which is relevant considering the social element interest of the case study area.

4.1.2 Agent-Based Simulation Modeling

An agent-based simulation modeling is a type of dynamic simulation modeling. The essence of this simulation lies in designing individual behavior at the micro level of separate agents that can represent different elements of a system, such as groups of people. The collective behavior of the agents arises from their communication – interaction with each other and their environment, creating certain dynamics of the system they represent or observable patterns at the macro level. An example of such observable patterns can be traffic jams that arise from the movements of car agents. By programming these rules of interactions, ABM allows the exploration of the effects of micro motives on the macrodynamic of the system or phenomenon in question. These characteristics of ABM, referred to as "emergence" (this term is explained more in chapter 2.2 "Model Design of Complex Constructs:

Where Hindrances Emerge"), are useful, especially in cases where due to the high complexity of a system, analytical models are not sufficient as they require mathematical representation of some rules such as agent interactions, even though such rules do not always exist. Moreover, such traditional methods often overlook emergent behavior. Therefore, as decision-making is facing complex problems, tools like ABM may provide better insights into the behavior of the system in question that other methods fail to capture.

4.1.3 The "IT" Artifact

As the "design and creation research strategy focuses on developing new IT products, also called artifacts" (Oates, 2022), the main artifact of this thesis is the simulation model designed for knowledge generation about the accessibility system to support DM in the context of regional development of Sundsvall's region of Sweden. To achieve that, the thesis creates a research framework for interpreting complex concepts and deploys the framework in this research in the process of model design in order to guide model development by the extraction of a set of key model variables. These variables are used as the basis of the model, i.e., the developed framework governs the design of the main IT artifact – the implemented simulation model.

One of the reasons for simulation (besides the negative trend of population decline in sparsely populated remote areas and the need for a visual tool to assist decision-makers with making priorities when planning for accessibility for regional development), as the research progressed, showed up to be linearity in decision-making. By this, I mean the fact that while complex real-world systems, such as the one that this thesis deals with, experience changes, adaptation to the environment, and self-organization qualities of the methodology exhibit non-linear outcomes that often cause doubts in model credibility. As mentioned, this often happens due to mental models of humans not being wired to contra intuitive scenario developments (Sterman, 2000). Therefore, the IT artifact represents a simulation model designed on the one hand to analyze and simulate transport and land-use accessibility effects within a regional context, and, on the other hand, to

generate insights that can empower decision-makers with a knowledge-based visual representation of possible consequences of their policies. The accent on the linear approach is done to draw attention to the fact that regional areas, that the planning is done for, miss a disregarding them as complex systems with intertwined internal structures, where pulling a string on one side could potentially cause ripples on many connected nods in the whole region. This type of connection is not covered by traditional analytical or statistical methods, but a complex system approach can address this complexity.

4.1.4 Why another model?

According to Railsback and Grimm (2019), the usual way an ABM model is designed is by throwing several submodels, each of which represents a theory. A theory connects assumptions that interpret a phenomenon under the same frame systematizing knowledge to explain, predict, or understand the meaning of the phenomenon (Tebelius & Patel, 1987). Here, a concept of a model links theory to the reality that this theory describes. In this meaning, theory strives to reflect reality, while a model represents a simplified picture of reality. Such a picture does not have to be strictly related to the actual reality as a theory is, but by reducing details non-essential for the study/problem context, it helps to understand the reality even in the absence of a ready theory.

Within this thesis, a theory reflects a specific behavior of an agent(set)and is the reason for using ABM in the first place as the latter allows a researcher to model individual behavior. Even though most submodels do not include all system characteristics that impact a model, they comprise certain processes with essential characteristics for their intended use - the purpose of a specific model. Therefore, as “almost every ABM requires new theory for a new behavior or context” (Railsback & Grimm, 2019), a model related to a specific context aiming to answer the research questions will be most often a new model. By doing so a researcher assures that the model fulfills the research aim and can be used to answer the research questions in the given context. Submodels, however, do not have to be brand new but can be loaned from existing research/literature when reasonable for the research.

4.2 Philosophical Standpoint

4.2.1 Ontology, Epistemology, and Methodology

Any research conducted by humans bears signs of their participation (Guba, 1990). Research is therefore inevitably influenced by the extent of subjectivity naturally imposed by human presence in it and by the development of knowledge that such research is set for. Thus, it is important to state the individual beliefs that contribute to knowledge development to allow the judgment of paradigm stakeholders to be transparent. What does it mean though? Such influence of own beliefs on one's research supposes that any human construct, such as knowledge, would be taken into a specific direction based on many factors that define us as humans. An example of such a factor can be a cultural background which may affect the choice of variables for modeling a social system. The attention to certain variables over others can be assigned to our subjective experiences, i.e., the events and factors that most prominently affect our own lives. The research must therefore be clear about the researcher's view on what (s)he defines as knowledge and the way the knowledge is created for each specific research problem.

A researcher's worldview or paradigm is characterized by the approach to defining the three pillars of a paradigm as a set of beliefs: ontology, epistemology, and methodology. Guba (1990) explains that paradigms define what we know as our "basic set of beliefs that guide action"; ontology defines researchers' belief about "how things really are" and "how things really work" (ibid.), epistemology asks for the origin of knowledge, justification of beliefs, and rationality (Godfrey-Smith, 2003), and methodology defines how the inquiry should proceed (Freebody, 2002). Therefore, this research places a philosophical standpoint in the methodology part, since I find my definitions and ideas about knowledge tied to the way I chose to approach the research, i.e., the research method, as the key influence on the philosophical stance. Naturally, the choice of the methodology is itself derived from the "needs" of a thesis, namely, the objective and the research questions that pave the way to reach the objective. This approach to adopt a certain stance or a combination of stances reinforces the idea that the same researcher may have different philosophical standpoints in various endeavors not solely due to the

method choice, but also depending on the problem context, and the research questions that they seek to reply. Therefore, I am cautious with defining the stance as a "choice", since it is not only my personal worldview detached from the specific research or its context that defined this "choice".

Due to the applied simulation modeling method and the research objective to study the system and its behavior, I allow empirical data embedded in the system to steer the research generating knowledge from empiricism to theory, viewing the simulation outcomes, and iterating in the process. This allows the model to reflect new information gained from the research. The use of the *abductive approach* is therefore reasonable for this work that revolves around learning from a complex concept, "developing theoretical explanations based on emerging empirical observations" (Modell, 2009). An abductive knowledge approach is known to start with observations to define hypotheses or explanations that fit the observed phenomena, unlike deductive reasoning (from general to specific) or inductive reasoning (from specific to general). Thus, abductive reasoning is about forming the most appropriate explanations based on available evidence. The system behavior is explored as it emerges from unpacking the complex concept into key components, which interact allowing the modeler to explore the dynamics of the modeled system. The behavior of the system lays the ground for further research, which in turn generates new ideas that are put back into the model, this way enriching the model and knowledge about the system that it reflects.

To explore the approach deeper, I need to address the quantitative research that simulation modeling is associated with. Creswell (2014) places the core of quantitative research in postpositivism, supporting the idea by the way the approach has been historically designed. Maksimović and Evtimov (2023) explain that the reason for associating it with a positivist paradigm lies in "the basis of which is cause-and-effect relationships, as well as the questioning and verifying of existing theories" as both notions are believed to share the same "basis" in research – the way the assumptions are made. Both notions support the idea of objectivity of knowledge creation and rigor measurement. As the paradigm develops into postpositivism, which treats knowledge extension in a less naïve manner by accepting the subjectivity of

research, the opinions of scholars start to split. Interestingly, Maksimović and Evtimov build up on the fact that as postpositivism leaves more room for subjectivity, thus the paradigms can be more flexible, defining a mixed method (combination of qualitative and quantitative) approach as a home environment for postpositivism.

Another point to consider is the scope of the IS field, which is not strictly defined as to what disciplines it covers. Having historically originated from engineering and data science fields, the literature of the later 20th century that defines the IS standpoint is subject to update. Due to this fact, current research cannot directly refer to the older scope of the field without mentioning broader ethical and philosophical considerations injected by adjacent and often integrated fields of artificial intelligence, machine learning, and human-computer interaction (HCI), as their area of expertise goes beyond technical and engineering considerations of the earlier years. According to the authors Holl and Maydt (2007), the epistemological view on IS is on its own an explicit application of a cognitive process to acquire knowledge since the process of designing a software artifact is systematically defined. This definition suggests classifying epistemological considerations down to naïve realism, critical realism, evolutionary epistemology, moderate constructivism, and radical constructivism. However, this definition of the IS objective leaves room for discussion as it states that "the aim of information systems, the science of systematic information processing in enterprises, is to develop business information systems", which reduced the scope of the ever-growing subject field of IS. As much as I agree with the statement of the authors mentioned above, who argue that "there is not a single particular epistemological approach which is suitable for every kind of object of cognition" applicable to the whole field of IS field, the existing clustering of philosophical IS stances can be rather excluding for many scholars in the area considering, for example, the latest advance in HCI areas and the emerging need for ethical studies. The expansion of the Scandinavian IS field and its integration into social sciences has given rise to studies in diverging paradigms as the discipline encompasses scientists who are "interested in relations between humans, computers, and organizations." (Flensburg, 2017).

At the beginning of my journey due to my background in IS which back at that time was a part of data science and had inherited its major traits and properties, I viewed myself as a designer of an artifact, who would do the research in an absolute objective fact-based manner. Therefore, prior to embarking on this journey, my contemplations on a researcher's philosophical worldviews and their influence on the research were rather restricted, leaving little room for pondering on the need for interpretations or underpinnings of assumptions (e.g., assumptions, that guide the reduction of the reality for model development). Simultaneously, my initial belief was that the philosophical approach is tied to the person and cannot vary between the studies conducted by the same researcher. However, this shifted when I first started to develop submodels and test how well each of them represents a feature or function of a part of the simulated system, and whether to discard or keep each submodel. I realized that in this case, the approach would be closely related to a constructionist stance as I study emergent patterns and root new knowledge in the interpretation of the simulation results based on the gained insights from simulation and model design. Later, as my research advanced, I found this stance most appropriate, the more my artifact became rooted in the interpretation of the explored phenomenon, as the developed framework and ABM model were oriented on acquiring knowledge from the practical experiences of decision-makers.

4.2.2 The Methodological Approach of Simulation Modeling

It would not be honest to ascribe only the quantitative approach to the whole thesis. Even though, simulation as a method is often viewed as a quantitative method as its input and output are based on quantified data (Eldabi et al., 2002), the essence of major interactions in the model that contribute to the simulation outcome are not purely quantifications in terms of used data. The key variables are developed at a high level of abstraction based on empirical research, but their weights and values are implemented with the freedom of adjusting these parameters to study the effects of different variable interplay.

Especifically, since the model explores patterns of dynamical changes, their effect on the elements of the system, and the interpretation of a concept embedded in the model design, the characteristics of qualitative research come into play. Qualitative research often deals with concepts that are ambiguous and hard to understand with quantitative tools as the latter do not focus on the in-depth underpinnings of a phenomenon. Such an approach of integrating qualitative approach is used in this thesis as well, e.g., when the key variables for modeling are extracted through analysis of the associations that decision-makers expressed when asked what the modeled concept meant for them. The constructivist lens ties up the different parts of the thesis that apply qualitative or quantitative approaches through developing knowledge generated by understanding social interactions, that are given meaning (Yilmaz, 2013). Therefore, in different parts of the thesis, this exploratory approach creates new knowledge allowing the constructs (of knowledge) to emerge. This idea of constructing knowledge about concepts through the eyes of the individuals and their perceptions in the qualitative part of the thesis (Brinkmann, 2020) is in line with the quantitative part of the thesis that explores the dynamic conjunction that the individual perceptions result in.

While initially defining the simulation as a quantitative method due to the utilization of numerical values, upon deeper reflection, I started to question whether the simulation modeling approach of my research only aligned with the quantitative methodology. Although numerical inputs are necessary for computational purposes, the focus of my simulation is not on quantifying the effects of these inputs on the system's characteristics as such. Instead, the analysis of simulation results reveals emergent dynamics that illustrate a phenomenon of agglomeration economies and spatial clustering. This suggests that this research may be better categorized as a fluctuation between the quantitative and qualitative approaches depending on which part of the research the reader looks at each given moment. Even though building a model depicts characteristics of a quantitative approach, it incorporates at the same time qualitative aspects, as the simulation results prioritize the description and interpretation of complex system behaviors over numerical quantification. Thus, the thesis swings between qualitative and quantitative approaches.

Given the considerations above, the overall philosophical lens of the thesis can be described as a constructivist with an abductive approach. By treating simulation in this thesis as the main method the idea is that it ties up the substudies (papers) together (I do not use the same method in each paper, but modeling the system and running simulations on it deploys relevant methods that assist in building up a system, defining the variables, interpreting their behavior, etc.). Therefore, the abductive approach to generating knowledge is reasonable in the context of this thesis. One example of the appropriateness of the approach is the way the system components functionality (agent behavior) is researched and modeled as the "agents that combine experiments with consultation" (Addis & Gooding, 2008), meaning that the system design is improved as the research progresses when more research becomes available. At the same time, the way the model behaves in its turn also affects the following research direction.

Even though by adopting a specific paradigm, the research results are influenced, clarity about what worldview the research is associated with helps to "illuminate the quality of findings that support scientific studies and identify gaps in generating sound evidence" (Park et al., 2019). Another point to consider is that by choosing to develop a model one is inevitably thrown a step away from reality by the necessity of simplifying the system that is being modeled. This demands a further round of assumptions and considerations of what parts of the system are important to be reflected in the model, which becomes a construct of a researcher. Apart from that, the concept unpacking approach towards forming model variables treats knowledge creation as a concrete context-tied construct designed for solving a specific problem. Finally, the artifact uses self-organizing characteristics of ABM allowing system behavior to emerge from simulation, thus the construct of the simulation outcome becomes embedded in the interpretation of the model developer. Therefore, the overall stance of this research is closely related to constructivism based on the designer's personal views, interaction with decision-makers in the field of application, and treating the simulation environment as the experiment setting for emergent system behavior for the objective of this thesis.

To summarize, I adopt an *abductive approach* through the stance of a *socially constructed reality*, which I use in my thesis to incorporate expert interpretations of a complex concept that serve a pragmatic reason – to design a research framework that enhances the adoption of simulation modeling in complex system domains through the capabilities of model development. The research framework addresses the ambiguity and complexity of the case study problem of accessibility, which is an integral part of sustainable regional planning and informed DM.

4.3 Research Design and Material

4.3.1 Materials, Methods and Data Collection

This thesis utilizes a diverse range of empirical and research materials: semi-structured interviews, group discussions, policy documents, material from workshops, feedback from seminars, statistical data, and research literature. The selection of material is relevant to the objectives, research questions, and methods of this thesis and its included papers.

Figure 2 illustrates this development of the studies as per the included research paper, their correlation, and the inclusion of the case study. It demonstrates how the papers comprise the case study relevant research via extracted shapes – the size of the shapes does not however reflect the proportion of the case study-related research of the respective paper (the case study parts cover issues related to regional planning for accessibility). The rest of the papers – the blue part inside the squared forms address the issues with complexity and simulation modeling (including PM). The figure demonstrates the structure of the papers regarding the research progress from Paper I to Paper IV, i.e., how the results and contributions of each paper lay the grounds for the papers connected to it. For example, the extraction approach of Paper II and discrepancies among the DM on concept

interpretation created the basis for researching the complex concept interpretation opportunities that Paper III took over and explored.

This way, the research design addresses the thesis' objective in several consecutive steps based on the insights from previous steps to ensure that the aim of the thesis is constantly monitored, and relevant to the choice of methods and materials. Thus, from the initial study, a series of adjustments and a shift of focus were introduced to ensure that the conglomerate of the

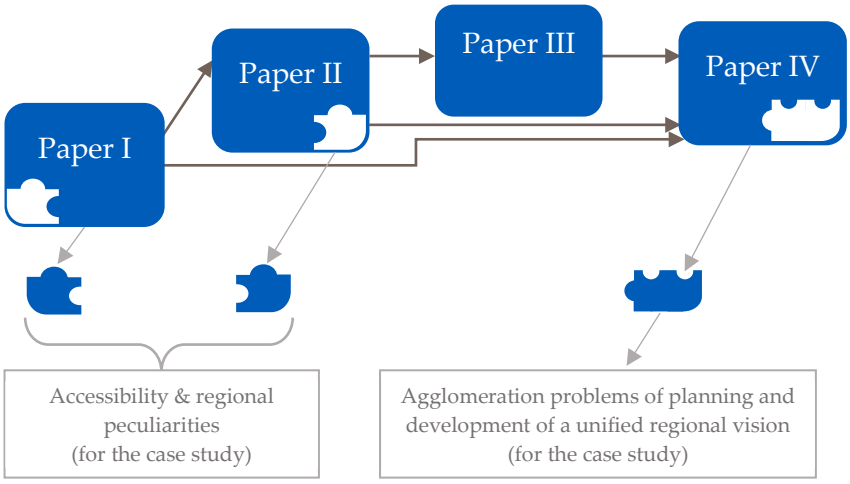

Figure 2: Development and structure of the included papers

included papers followed the thesis' objective. Thus, the objective of the thesis was shifted during the research. However, upon reflecting on the research progress below, the shift can be more properly described as defining the scientific niche that the thesis occupies within the subject field of IS. I, therefore, further elaborate on the approach and development of the research design in the subsequent paragraphs.

The use of the case study problematizing regional accessibility as a part of sustainable development is feasible for this research due to the complexity of the problem and the need for a holistic perspective on this phenomenon from planning and decision-making perspectives. In the IS field, by generating theoretical underpinnings from the practice, a researcher explores the "why" and "how"s of a complex problem, and incorporates in-depth

insights into contemporary problems that arise in the multidisciplinary field of IS (Benbasat et al., 1987).

Table 1 outlines the research design of the included papers, consolidating their methods, materials, and research questions. It shows the relation of the RQs (research questions) of the included papers to the RQs of this thesis. As papers I and IV do not include concrete RQs, I formulated their RQs in the table based on the objectives of the respective papers.

Table 1. Outline of the research design of the included papers

Paper	*Method*	*Materials*	*RQs of the Paper*	*Relation to Thesis'RQs*
Paper I	Scoping literature review	16 selected papers	RQ1: How can regional accessibility be evaluated? RQ2: What are the requirements for a system that can handle current challenges and address accessibility?	RQ 1: How can the complexity of accessibility and its evaluation be addressed in sustainable regional planning?
Paper II	A six-step thematic analysis *(empirical study)*	20 respondents representing regional municipalities	RQ1: How is the concept of accessibility understood and interpreted in regional areas? RQ2: How can decision-makers integrate key accessibility variables that define regional accessibility?	
Paper III	Problem-centered literature review	10 selected articles	RQ1: What key challenges are associated with ABM and SD models designed to support decision-making? RQ2: How can model design address these challenges to enhance the usage of models to deal with complex concepts?	RQ 2: How can the perspective of complex systems and concepts facilitate the adoption of simulation modeling as a digital practice in decision-making?
Paper IV	ABM simulation *(based on empirical and*	Synthesis of empirical data, research framework, preceding included	RQ1: How can regional planning overcome the segregated municipal planning approach and incorporate the regional vision to handle contemporary	Both RQ 1 & RQ 2 of the thesis

	theoretical insights)	papers & simulation results	challenges and peculiarities of regional areas? RQ2: How can insights from contemporary methods allow planners to consider the long-term consequences of their approaches?

The subchapters below elaborate on the methodological approaches and data collection of the included papers in more detail.

4.3.1.1 Paper I.

The entrance point of the research was the initial literature review. Since the practical problem that made this research possible came from the table of decision-makers who were struggling with planning for sustainable regional development from the perspective of one of its components – accessibility, the big portion of that review focused on exploring their challenges. The adoption of a literature review in this research is justified by the need to thoroughly explore and understand the existing knowledge base surrounding accessibility and simulation modeling. The reason for resorting to simulation modeling came from the defined prerequisites of the tool that is capable of supporting decision-makers in the context of their problems. Given the complex nature of the problem and the stage of the research, a scoping review was particularly appropriate (Munn et al., 2018) as it helps in identifying knowledge gaps, clarifying concepts, and mapping the extent of existing literature, which aligns with the goal to understand the challenges of the case study and the prerequisites for an effective decision-support tool. This initial review helped in outlining the scope of the literature and refining research questions, providing a solid foundation for further research.

By exploring the scientific databases Scopus and Google Scholar in a search for the articles that tackle the problem of defining, measuring, and evaluating the case study problem, i.e., the literature about accessibility, how it is defined and evaluated, and literature about applying simulation

modeling that can help handle the challenges of "measuring" or evaluating accessibility. The study analyzed the contents of the selected papers to identify the state-of-the-art and the prerequisites for a system that has the potential to overcome the defined complications that the study had discovered. The content analysis was conducted on sixteen scientific publications, which consisted of peer-reviewed journal articles, conference proceedings, discussion papers, and a research report.

4.3.1.2 Paper II.

As the previous paper identified certain disparities regarding the use of the accessibility concept and suggested a possible system to handle the existing challenges, the subsequent study dived into the qualitative study design to deeply explore and understand the experiences of the planners and include their expert vision into the method (Creswell, 2014). This was achieved by incorporating empirical data gathered through two different interactions with the decision-makers active in the field of accessibility planning: first, by addressing representatives of five different municipalities within the case study region of Sundsvall, and second, by completing the first interaction with the feedback gathered during a workshop with fifteen representatives of the municipalities within the region. Data analysis was conducted through the six-step thematic analysis developed by Braun and Clarke (2006). This type of analysis is well-suited due to its adaptability and depth in analyzing qualitative data. This method facilitates the identification and detailed examination of patterns and themes, providing insights into complex aspects of the research topic. It aligns the contextual interpretation of the concept with the study's objectives, supporting a thorough exploration of underlying themes and trends, which is reasonable, considering that the previous study showed a lack of consensus about the concept among planners. At the same time, reviewing the preceding paper, it became obvious that the analysis of regional peculiarities was not structured clearly, but scattered throughout the narration. To redress this miss, this second paper additionally summarized and expanded this part by adding more literature research and empirical findings from interactions with the practitioners.

4.3.1.3 Paper III.

Data collection and results from the first two papers demonstrated that there was a need to address the lack of consensus about the concept before modeling a complex system to evaluate it. Therefore, as the model development based on the insights from the first two studies was being designed, the need for a more comprehensive approach to approximate the model to practice and diminish the possible causes of method resistance, led to this third study.

Data collection for this paper was initially planned to be based on the evaluation gathered through interaction with the decision-makers. However, the occasion revealed the struggle that the participants experienced when evaluating the model prototype and its applicability. To address the underlying reasons for this challenge, the paper shifted to a qualitative approach to explore why such tensions arise and how they could be diminished. This study deployed the problem-centered literature review of the latest scientific articles where the possible reasons for the resistance were problematized in relation to the key factors that the authors associated with the use of simulation modeling in the practice of decision-making. According to Rowe (2014), this type of literature review is centered around a specific problem by grouping sources that address similar issues and filtering out the irrelevant ones. Due to the breadth of this approach, the findings, problems, gaps, and ways of solving these issues are identified. The data collection was performed by searching for scientific publications filtered from the initial search via Scopus by relevance to the problem of model understandability by decision makers and their resistance to the adoption of simulation models.

4.3.1.4 Paper IV.

This paper is a conglomerate of the preceding research as it bridges their theoretical contemplations with practical tools and applies the case study underpinnings to showcase the application of the artifact as the digital practice of simulation modeling that can assist regional planning. The research of the paper follows the design-oriented iterative process that covers

the four basic research elements of analysis, design, evaluation, and diffusion used in IS research (Österle et al. 2011). By aligning modeling with these principles, the study applies the unpacking framework via a synthesis of the PM and ABM capabilities, thus drawing on the empirical and theoretical insights for the specific case study problem of understanding the effects of segregated municipal planning for accessibility within regional development. Brendel et al (2022) define research as a design-oriented process as long as it deals with developing an artifact in order to approach a certain problem.

Paper IV deploys the insights gathered through a series of interactions, workshops with stakeholders, and policy document reviews, enriched by theoretical contributions and practical tools of the three preceding papers (the major elements from the included papers: framework, variables, regional challenges, modeling prerequisites). The empirical data of this study includes material collected via several interactions with planners, policy documents, literature research, model development, and simulation results. This was conducted to narrow down the case study problem with the help of the insights gained via data collection that depicted gaps in collaboration between the stakeholders. Therefore, the model was oriented to explore the unfolding consequences of existing accessibility approaches at a larger scale that is currently overlooked by planners – the regional one. ABM simulation was applied as it answers the requirements for the method defined by the first study. The method used the defined key variables to model the unfolding consequences of planning with the existing planning approach towards accessibility – the agglomeration of opportunities. The concept was formulated based on the variables extracted through the second study, and the framework that the third study developed to enhance the adoption of simulations in practice and counteract the hindrance towards its application. The design of the model followed the principle of the trade-off between simplicity and representability of the model as its "balance is realized by creating simple computational models and simple experimental designs which meet the purpose or intent of the study" (Burton & Obel, 1995). Upon closer consideration of previous research, policy documents, and existing challenges of the case study, the paper incorporated several scenarios for simulation. The scenarios were developed to address the current shortsighted

segregated municipal approach to planning with the principles of the agglomeration theory to visualize the outcomes of regional planning approaches.

4.4 Ethical Considerations

In this thesis I adhere to the principles that the Swedish Research Council (Ethics in Research and Good Research Practice, 2019) elaborates on to comply with the good conduct practice associated with research: reliability that safeguards the quality of the research and is reflected in the design, method, analysis, and use of resources; honesty in developing, implementing, scrutinizing, and reporting the research and informing others about it in an open, fair, complete and objective way; respect for colleagues, research participants, society, ecosystems, cultural heritage, and the environment; and accountability for research from idea to publication, for management and organization, for education, supervision and mentorship, and for their wider consequences.

As the research aims to develop knowledge, and the field of IS revolves around digital practice and its societal implications, it is important to disclose how the specific ABM type of simulation was used to ensure the accuracy of the artifact to potentially reduce the question of unethical and non-transparent research conduct. This can be ensured provided that the model development follows the principles of validation, verification, and replication, which enhance the model's credibility, and understandability and facilitate its adoption (Wilensky & Rand, 2007). One aspect of the enhanced transparency and credibility of ABM as methodology is a comprehensive technical protocol - Overview, Design concepts and Details (ODD) - developed specifically "for providing a consistent, logical and readable account of the artifact" (Grimm et al., 2020). As mentioned in the chapter of this thesis about the theoretical lens, the guidelines developed for the rigor of modeling in research by Rand and Rust (2011) are included in the ODD protocol, and the latter is developed as an annex document to the simulation model Paper IV.

Two of the four included papers use empirical material gathered through a series of interactions with the stakeholders. More specifically, data from Paper II was received from the municipalities and the replies were not connected to any individual who were responsible for their preparation. Additionally, the paper included data collection during a workshop where stakeholders were split into groups, and the empirical data was presented in the form of pictures where the groups wrote down their ideas without indicating group members. The ideas expressed during this workshop cannot be traced to individuals who wrote them down. Paper IV includes a wider range of empirical data, for example, workshops and discussions. However, except for the included material from previous research, this collection concentrated on the width of the material rather than the depths of each document or feedback paper. Therefore, I conclude that the ethical aspects of the research can be considered sufficient and adequate for this work.

5 Results

This chapter presents the research results that guided my path, paved by the exploration and development of theoretical insights, research framework, and simulation model.

5.1 Short Summary of Key Results

The thesis deploys the model-based approach to exploring complex systems and concepts to enhance the adoption of simulation modeling into the policy design stage, fostering informed DM that generates insights into the problem in question. To accomplish this, the thesis explores the concept of regional accessibility from the perspective of a complex system. This way, this work enhances the adoption of simulation modeling as a digital practice by developing the research framework that assists model development. The main advantage of the framework lies in the development of a concrete approach with specific steps for extracting key variables that are the basis of a model build-up, bridging the gap that previous research left between theoretical foundations and practical modeling, thus moving beyond general principles of model development. The framework functions through successive loops that, on one hand, unpack the concept creating concrete variables, and on the other hand, add value to the top concept by splitting the top concept into less vague associates that contribute to a better interpretation of the top concept. The case study of the thesis applies the unpacking framework by using the empirical data gathered through interactions with the decision-makers involved at different levels of decision-making regarding regional accessibility. The research extracts key building blocks of accessibility that the decision-makers associate with the concept and uses these blocks as variables for a simulation model. This way of unpacking complex concepts into constituent components that can be more easily interpreted and implemented in a model, the research provides new information that can help understand the characteristics and components of the main complex concept through an added value feedback loop. This way,

the complexity associated with the top concept can be expressed in less vague terms and variables, which makes it more manageable and interpretable for decision-makers and model designers. Consequently, the utilization of simulation modeling as a learning tool to generate knowledge about the problem in question can diminish the reluctance of decision-makers to adopt the digital practice of simulation modeling for its intended purpose, namely, to gain insights into a complex problem.

The approach of the thesis incorporates the perspectives of the key model stakeholders for whom the artifact is designed. This can help reduce the resistance towards applying modeling as a learning tool in DM, which often overlooks the application of digital practices, specifically simulation as a credible tool that can add value to the understanding of the problem that DM faces. By applying the above-mentioned approach to DM in the field of regional transport accessibility as a case study, the thesis strengthens IS as a cross-discipline thus rooting the position of the IS in disciplinarian pluralism.

A summary of key results of the included papers is given in Table 2. As papers I and IV did not explicitly state the RQs, I introduced those based on the stipulated objective(s) of the respective papers to answer their objectives.

Table 2. Summary of Key Results of the Included Papers

Paper	*Results*	*Short answer to Each Paper's RQs*
Paper I – the Prerequisites Study	• Expanded and categorized set of accessibility measures • Regional accessibility indicators per measure • Peculiarities of regional areas (dispersed in this paper, thus they are organized in paper II) • Prerequisites for a system that can address the complexity and the case study problem	RQ1. Short answer – by using a set of accessibility measures and indicators and/or integrate dynamics simulations for analyzing policy impact and interdependencies RQ2. Short answer problem-appropriate abstraction, clear visualizations, behavior modeling, and integration of ABM & SD to reflect real-life dynamics and support decision-making

Paper II – the Variables Study	• Challenges & goals of regional areas • Structured regional peculiarities • Breaking down of accessibility concept - the set of key variables associated with the concept based on the practitioners' interpretations	RQ1. Short answer – through the range, travel time and attractiveness of destinations RQ2. Short answer – By planning for regional development through destinations considering their key characteristics while addressing reliable transport, stakeholder needs and regionwide cooperation
Paper III – the Framework Study	Research framework for unpacking concepts that are addressed within the complex systems. The framework comprises the concept unpacking curve that generates concrete variables and concept interpretations and five principles that govern the framework application.	RQ1. Short answer – reaching consensus on concept definitions and key characteristics to ensure reliable model design RQ2. Short answer – through the developed complex concept unpacking framework
Paper IV – the Model Study	• Unified regional vision development for stimulating cross-municipal cooperation • Application of region-tied approach to inform knowledge-based planning • Aggravated effects of increased accessibility approach in regions that disregard collaborative planning and create intraregional competition (important societal implication) • Application of the research framework from paper III to explore the capabilities of the complex concept unpacking tool in a complex domain of regional planning	RQ1. Short answer – visual capabilities of ABM RQ2. Short answer – cross-municipal planning via ABM and complex concept unpacking framework that engages stakeholders

5.2 Results from the Included Papers

The current subchapter elaborates on the individual results from the included papers in more detail. Each paper briefly covers its limitations. More details about the limitations are included in subchapter 6.4 "Handling Limitations" of this thesis.

5.2.1 Paper I

The article "Accessibility Measures and Indicators: A Basis for Dynamic Simulations to Improve Regional Planning" defines measures and indicators of regional accessibility to inform planning for sustainable regional development, as well as prerequisites for a system that can illustrate the consequences of policymaking. The focus of this study is accessibility, its evaluation, and the prerequisites that a system or a tool needs to conform with to be able to address the complexity of the accessibility representation.

This paper has several important contributions. The first part relates to defining the prerequisites or requirements for addressing the case study problem. By reviewing the current state of the art in the field of evaluating accessibility, it adheres to the perspective that can handle the concept by treating it from a complex system perspective. Next, it lifts the three important evaluation components of accessibility: accessibility measures, indicators, and theoretical requirements that guide the choice of accessibility indicators. The results of the paper define the method that is appropriate for incorporating the insights from current challenges with accessibility evaluation, namely simulation modeling. The paper extracts three major points that a model of the case study problem needs to adhere to: an appropriate level of abstraction, easily interpretable results, and capabilities to represent individual behaviors of system objects.

The next contribution relates to accessibility evaluation. The paper summarizes the current set of measures and presents a review of their role, and evaluation example alongside the advantages and disadvantages. To

incorporate the existing and contemporary elements of accessibility evaluation, it expands the current set of measures with environmental impact-related ones (Rasca & Høgli, 2021) and categorizes each set by main descriptions of the accessibility components. The revised structure is presented in Fig. 3.

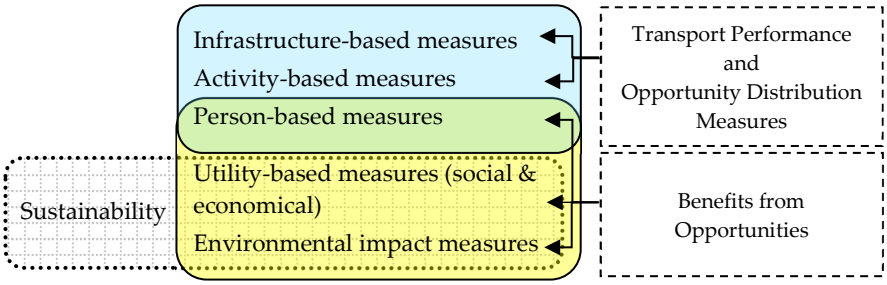

Figure 3: Structure of accessibility measures

Throughout the paper, as the specific conditions relevant to the peculiarities of regional areas are discussed and highlighted, the paper analyses the existing indicators and based on the defined peculiarities and reviewed measure categories develops a set of region-specific accessibility indicators. This simplifies their future application or adjustment since due to the capabilities of the simulation methodology deemed as fit for the study purpose, some "hard to measure" indicators were often omitted for evaluation simplicity. As the defined tool of simulation modeling can cope with the measurability problem of such indicators, the theoretical criteria (Morris et al, 1979; Geurs & van Wee, 2004) stipulating the selection of measurable indicators, can be omitted as restrictive, thus ensuring that no description of accessibility meaningful for the phenomenon has been overlooked in the evaluation.

An important contribution of this study apart from the exploration of regional peculiarities and indicators is the placement of the latter in a respective accessibility measure category. The advantage of such grouping enables the selection of indicators based on the study needs in relation to what each measure provides. For instance, Geurs and van Wee (2004) exemplify

congestion indicators ascribed to infrastructure-based measures, highlighting that these types of measures can represent a transport system capability (but exclude land-use effects).

To sum up, this study provides insights into the capabilities of a simulation method that can exceed the capabilities of existing approaches to evaluating accessibility, pinpointing the peculiarities of regional accessibility that such a method must consider. The analysis shows inconsistencies in the definition and evaluation of the accessibility concept, which often largely varies depending on a study context and measurability of indicators, causing discrepancies in the practice of regional accessibility planning (e.g., the chosen indicators may overlap to a certain extent).

Paper I briefly addresses limitations in its chapter 1 "Introduction" regarding the scope of the study focus area, and in its chapter 2 "A System Theory Perspective" regarding the specific perspective fit for accommodating the challenges of accessibility evaluation.

5.2.2 Paper II

The article "Accessibility in sparsely populated remote areas: Key variables for informed regional planning" focuses on the interpretation of regional accessibility concept by practitioners (DM and planners). Based on the insights about the complexity of accessibility definition and application in praxis from the preceding paper, the study uses the experiences of practitioners to create a common picture of key factors associated with regional accessibility to highlight the vital elements of the concept. Apart from diving into the interpretation, the study also explores adjacent challenges of the concept, such as peculiarities of regional areas to ensure that the specific needs and challenges of these areas are identified and incorporated in the discussion around the concept-related problems and planning for it. To formulate the basis for this, the paper refers to the preceding study where the peculiarities were defined throughout Paper I, but were not accumulated or structured. The synthesis of both these aspects is critical to inform planning

specifically in the case study region of sparsely populated remote areas that already suffer from limited resources and drastic population decline (paper II). The following key aspects of the mentioned areas were formulated:

- Sensitivity to infrastructural changes
- Representation of individual perceptions of accessibility
- Efficacy of transportation and land use
- Time lag
- Break-down of the concept of accessibility in the context of regional access to goods, services, and destinations

Another aspect identified by the previous study required a tool fit for this research via dynamic simulation modeling based on key characteristics of the system in question. Therefore, by extracting key associates of accessibility, the paper identifies the variables upon which such a model can be built. Provided that dynamic simulation modeling, specifically ABM and SD allow for various levels of abstraction, the research ensured that even highly imprecise concepts, such as accessibility, can be represented through variables that are not necessarily easy to measure. The results of the thematic analysis of empirical data are summarized in Table 3 below:

Table 3. Summary of primary themes and sub-themes

Theme 1: Developing destinations as a point of attractiveness
Sub-theme 1.1: Attractiveness of destinations
Sub-theme 1.2: Time to and from a destination
Sub-theme 1.3: Range of destinations
Theme 2: Ultimate goals of increasing regional accessibility
Sub-theme 2.1: Reliable and quick transportation infrastructure
Sub-theme 2.2: Planning with the needs of stakeholders in mind
Sub-theme 2.3: Growth of existing and new enterprises and population
Theme 3: Challenges of planning for regional accessibility
Sub-theme 3.1: Regionwide cooperation policy
Sub-theme 3.2: Unrealistic expectations of allocated resources and time frames

The interpretations of accessibility that can be directly adopted as key variables for modeling were formulated as the sub-themes 1.1-1.3. Since they

are consistently related to the description of destination-related characteristics, the DM approach to regional accessibility is interpreted as planning for physical opportunities in terms of their attractiveness, proximity, and range. The need for this concept interpretability was supported by the fact that the data collection process exposed how cautious the planners were in defining the concept, and in most cases used it interchangeably with attractiveness.

The analysis also yielded the need for improving the current accessibility planning approach specifically in less urbanized regional municipalities (nearby more densely populated regional areas) that are largely dependent on reliable transport infrastructure. The paper highlighted the challenges of regionwide planning, as municipal-level planning efforts are largely at risk of being disregarded in the absence of a strong unified cross-municipal support that can function as a joint driving force for the "long-term attractiveness and growth for the region" (respondent E from Paper II).

To sum up, the study used empirical data to unpack the ambiguous complex concept into more interpretable and manageable associates that could be directly translated into a set of variables for a model. It summarized and structured the peculiarities of regional areas, that were discussed in the first paper. Based on the prerequisites that the first study defined in relation to simulation modeling as the system to address the existing challenges, the current paper extracted a set of specific variables from the empirical data that can be directly used as a basis to design a dynamic simulation model.

Paper II briefly addresses limitations in its chapter 5.3 which deals with the "Methodological Considerations and Further Research".

5.2.3 Paper III

The article "Unpacking complex concepts to enhance use of dynamic simulations" develops a research framework that assists in breaking down the abstract, ambiguous, or imprecise concepts that complex systems explore. Through a problem-oriented review of challenges in the application of

dynamic simulation modeling methods (mainly ABM and SD), the paper interprets complex concepts and engages stakeholders in the modeling process to redress the DM resistance towards the adoption of simulation modeling tools and results.

The paper investigates the potential sources of modeling ambiguity that can cause distrust in simulation modeling as a credible method from the perspective of planners and decision-makers. It consolidates challenges, contributions, and key factors that model designers problematized concerning applying modeling as a decision-support tool. By adhering to the complex concept unpacking idea of Paper II and its analysis that shows a divergence of opinions in concept interpretation by its practitioners, this paper generates a research framework to interpret such concepts and engage practitioners. The analysis of the existing challenges and controversies is structured and listed as a set of factors that need to be addressed in order to reduce the negative effects of resistance towards modeling from the DM.

The framework is formulated as a complex concept unpacking loop inspired by the SD loop principles. On one hand, the framework breaks down or in other words, unpacks complex concepts into more manageable associates that can be more easily interpreted than the complex overarching notion. On the other hand, the split into the related but "new" concepts, adds knowledge to the understanding of the ideas underlying the top concept, thus enriching it by feeding back the new associates back to the top concept interpretation through the added value feedback curve of the framework.

The unpacking loop is stirred by the five guiding principles developed based on the insights into the key sources of resistance that the study yields. A more detailed review of the principles is given in Paper III; the illustration of the framework is shown in Fig. 4.

The revisited key variable extraction loop can be applied in praxis as a usable framework to guide model designers in model design and decision-makers in understanding the concepts that they deal with. Similarly to the possibility of deriving ready-to-use variables in the preceding paper, this framework incorporates the views of practitioners and is expandable: the

unpacking loop can be iterated several times for generating variables appropriate for the abstraction level of the research where it is intended to be applied. The flexibility of the framework is an important trait that enables addressing a range of modeling options that vary from simple models with minimal coding and a basic set of variables and parameters to more detailed constructs, encompassing all models in between these extremes. Thus, such models can be both conceptual and/or implemented data-driven systems with multiple parameters.

Paper III briefly addresses limitations in its chapter 1.2 “Scope and Limitations”.

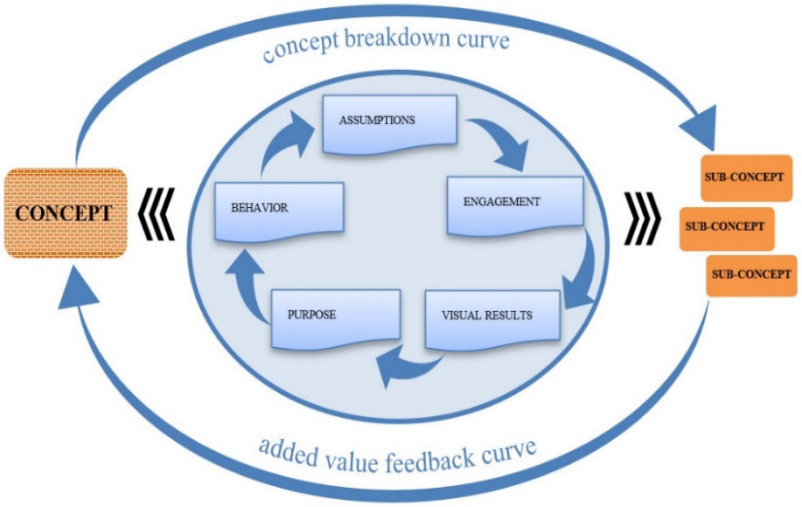

Figure 4: Visualization of the research framework for unpacking complex concepts.

5.2.4 Paper IV

The article “Towards a unified regional vision: Simulation to foster cross-municipal cooperation and planning” explores and deploys the potential of ABM as a dynamic simulation tool to create a unified regional vision for regional planning. This study designs a simulation model following the

complex concept unpacking framework and implements the model simulating dynamic changes in regional accessibility based on the agglomeration principle. The application of the framework serves two main reasons: it enables an easy-to-interpret formulation of a complex concept and engages DM in the model design. By engaging the DM in the model design, it resorts to the PM approach in order to assist DM in understanding the problem of accessibility better through the concept unpacking loop on one hand, and on the other hand, it illustrates the potential consequences of the segregated approach towards regional planning via ABM. The model incorporates the insights gained through stakeholder engagement in model development to focus on the dynamics of the regional accessibility system to inform the planners about the consequences of the segregated municipal planning approach. The simulation explores the interaction between destinations and their visitors, who evaluate the utility of visiting the opportunities that provide the highest agent utility for the minimal cost of distance (the longer the travel, the higher the "cost" to travel to that destination).

Consequently, the study results depict the daily commute decisions of population agents. The population agents' behavior consists of choosing a destination from a list of alternatives and interacting with it during their commute (travel). Agents' resources diminish as they approach their target destination that they chose by the trade-off between its level of attractiveness and the cost of traveling to it. The population agents gain the utility based on the attractiveness of the visited place before returning home. Thereby, the agents replicate people's daily decision-making processes and motions while engaging in various activities. If opportunities at the current location are not rewarding, agents relocate to another region.

The ODD protocol attached to this paper elaborates in detail on the principles of rigor of modeling in research (Rand and Rust, 2011) and of the principles that guide the development of the appropriate methodology, designing the model, constructing the model, and analyzing the model. The main design concepts are presented in Table 4.

Table 4. Main design concepts for the agent-based model of accessibility within a region

Concept	Description
Agents	Dynamic agents represent the individuals of a population that act through their lifetime. Static agents (patches) represent destinations. Their range and spatial distribution are user-assigned at simulation launch as one of the key variables of regional accessibility.
Interaction	There are no direct interactions between agents of the same type except for reproduction. Reproduction happens by statistical probability and new agents have initiation similarly to the setup of the original agents – except for the age set to zero, the placement and resource points are simple yet reflective of the population growth without gender split. Population agents interact indirectly via visiting destinations, which increases the visitor count and affects the utility points that overcrowded destinations give to following visitors. The interactions between dynamic and static agents are described by the following concepts.
Adaptation by choice	Agents seek to maximize their initial resources and choose destinations based on the utility they can gain by visiting a destination depending on its attractiveness and distance.
Resources	Resources represent the agent's level of satisfaction (happiness). To reach a destination, a population agent must spend its own resources, which every reached destination rewards by its attractiveness points.
Happiness	Dynamic agents can be either "happy" or "unhappy". Happiness is defined here as whether an agent can satisfy its utility goal. Unhappy agents emigrate with statistically defined relocation periodicity.
Distance	Each step toward a destination costs an agent a certain number of resources. This reflects the real-life time (or distance) cost to visit a certain place.
Attractiveness	The more attractive a destination, the higher utility it provides, and the higher an agent's interest to reach it. Destinations can implement a visitor cost penalty when overcrowded. This logic reflects the decline in the attractiveness of over-visited destinations.
Fitness	The fitness of population agents is derived from their initial resources adjusted after moving towards a destination by the resource points that result from the difference of those gained from the destination's attractiveness and lost by bridging the distance towards it.

Prediction	Although not at the forefront of the model, it allows agents to relocate if they are unhappy. This means that every relocation period triggers emigration for unsatisfied residents.
Stochasticity	It relates to birth and death ages, initial amount of resource points, range of agents and destinations including their placement, update sequence of agents, and relocation periodicity.
Dynamics	The effects of the individual choices of the dynamic agents form the dynamics of the spatial interactions within the regional accessibility system.

The results of agent interactions show that the patterns of population choice of destinations depict a strong preference for visits to larger destination clusters, causing abandonment of the smaller areas. In cases where overcrowding of destinations is included as an influential factor on destination attractiveness, the preferential patterns are not as strong as in previous scenarios since nearby alternatives are chosen because of the decreased attractiveness of overly visited destinations. This observation is however applicable only where the assumption of overcrowding negatively affects the attractiveness of a destination once the number of visits passes a certain threshold. The threshold is not empirically explored in this model and can be adjusted in its interface to explore what effects it produces. A demonstration of this preferential pattern is exemplified in one of the simulation runs in Figure 5.

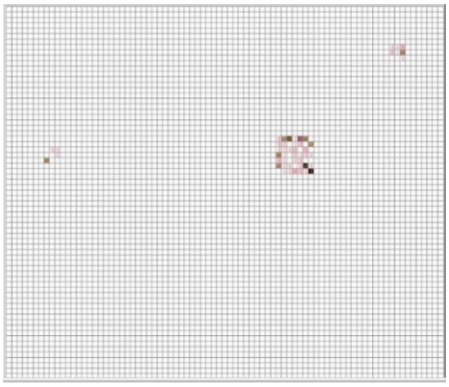

Figure 5: Prevail of preferential visits to larger destination clusters

Figure 5 should be interpreted as follows: the darker the color of the square, the more visitors this destination has, and the paler the color – the less visited the destination is. Consequently, the destinations of the smallest of the four clusters have totally disappeared from the figure – compare the structural dispersion of clusters with coloring to the conceptual model of the cluster centers in Figure 6.

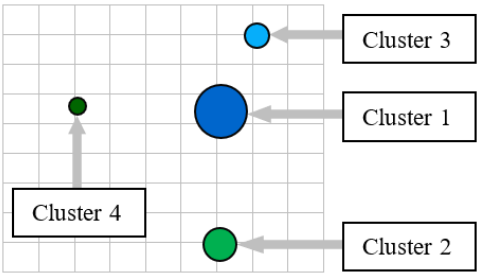

Figure 6: Four-cluster spatial distribution scheme

The explored four-cluster scheme reflects the application of the case study region of the six municipalities, two of which were merged with their closest counterparts that exhibit a distinct feature of a destination cluster and therefore dominate the area. This scheme is developed to facilitate dialogue with stakeholders for the recognizable approach of clustering centers and is therefore followed by a single and double cluster scheme for comparison of the preferential dynamics of population choices for various agglomeration scenarios. The single cluster destination dispersion happens around the only centroid of the most urbanized area in the region, which can be viewed as Sundsvall with the highest destination concentration. The double cluster scenarios depict the split between the number of destinations evenly into two centroids to test the effects of a decreased agglomeration approach between the single and the four-cluster cases with two centroids of similar opportunities. When the overcrowding effect as the agglomeration result is implemented in the single cluster scenario, agents are mostly socially happy. However, agents travel even less in the two and four-cluster scenarious, despite their overall contentment being significantly lower. The four-cluster example demonstrates that incorporating overcrowding effects improved

social content while only slightly increasing total trip distance, resulting in a more equal allocation of visitors across available possibilities. At the same time, with or without the overcrowding effects, the preferences in choosing certain destinations were clearly higher within the bigger clusters, signaling for the aggravated effects of the agglomeration approach towards planning for the destination dispersion.

These insights enable the initiation of the currently abandoned cross-municipal planning to explore the effects of a segregated municipal approach at a high level of abstraction, where the effects of agglomeration support the aggravated results of current DM approaches. The model enables regional planners to visualize and understand the long-term effects of their approach to planning for accessibility and the consequences that the approach has on the regional population dynamics. By actively involving planners in the modeling process, the study enhances collaboration across municipalities, encouraging a unified regional planning strategy that addresses common challenges and promotes sustainable development.

Paper IV addresses limitations and assumptions in its chapters “Design and development of the model”, “Conclusion” and “Contribution, Limitations and Future Research” (chapters 3, 7 and 8 respectively).

6 Discussion and Contributions

6.1 The Complexity Perspective: Model Design for Knowledge Generation

As this chapter discusses the results, it is important to indicate that while the implemented model contributes to the case study problem and the adoption of digital practices, the developed and deployed research framework represents the key contribution of this thesis. The reason for this highlight is derived from the discovered vagueness and lack of structured approach to model design from the previous research. Thus, this thesis advances the general steps in model design that PM suggests, contributing with concrete steps to the effort to answer the question of *how* complex problems and concepts can be interpreted and understood. Thereby, the complex concept unpacking framework advances the model design with defined steps and guiding principles. This equips model designers with the tool for developing concrete modeling variables to build a conceptual or implemented simulation model within a complex system domain.

Given the explored potential of model design to improve our understanding of real-world problems and complex concepts—not just through simulation results but throughout the entire *model development process*—this thesis contributes specifically to the model development part of simulation modeling. By focusing on model design as a means to provide valuable insights into complex (social) processes, as discussed by Gilbert et al. (2018), this contribution enhances our understanding of complex systems through one of the special methods of a digital practice. At the same time, the exploration of digital practices performed for the IS research field, which studies technology in the societal context implies that this contribution is not only seen from the perspective of its effect on society. Instead, the very development of technology and the adoption of a digital practice should incorporate the social perspectives and the views of the stakeholders, i.e., not only include their views to develop technology but envisage the effect that such development may have on society. The validity of such development (in

this case the validity of the model) and its implications is not easy to evaluate. Cooks (1983) elaborated on the idea of developing by stating:

> "So long as ultimate truth is not accessible, the process of assigning validity is social and partly dependent upon a consensus achieved in debate."

These considerations scratch the surface of the idea that technology and society need to be explored together. From the constructivist point of view, the line between the technical and social parts is blurred, as the process of researching technology is ascribed to the synergy of technical and social processes rather than defining only one construct. Despite the adoption of this stance and the incorporation of interpretations in the development and evaluation of the artifact, that builds new knowledge on the body of what is already known (Azizinezhad & Hashemi, 2011), the social construct is recessive in this research. The premise for that is that the thesis objective circles around the adoption and development of the artifact so that the method of the digital practice is elevated to the focus. This results in the technological part being somewhat overpowering, while its social counterpart can be seen as a weaker link in the research chain of this work and is mainly covered by the adoption of the PM lens.

6.2 Unpacking Complex Concepts to Reduce Resistance to Modeling

In both subject areas of the thesis (IS and Regional Planning), as the included studies and related research confirm, the challenge of adopting digital practices and relying on their results when dealing with imprecise concepts and complex domains is closely related to the problem of understanding and interpreting the complexity of the problem. Most of the resistance to digital practice methods originates from non-conformity between the dynamic nature of complex problems and the linearity of human mental models (Sterman, 2000), as the latter tend to ascribe one consequence to one cause. As a result of this tension, methods of digital practice such as simulation

modeling become often neglected. At the same time, there is an increasing demand for credibility, reproducibility, and replicability of research that adopts the entangled methods, even though the weakest aspect lies in the common challenge that both designers and stakeholders of the models share – the understanding of the problem.

Through the theoretical lens of PM that suggests the recommendations for model development (Belfrage et al., 2022), the analysis of Paper III for the resistance reasons shows that most of the reasons share the common ground of challenging interpretation issues. These issues relate to the problem of understandability and interpretation of the underlying problem, key model characteristics, and simulation results (what the results mean for the problem). Therefore, this research adheres to the case study problem of interpretation of the accessibility concept in regional planning. While the developed framework comprises both dynamic simulation methods of SD and ABM, the advantages of the ABM in modeling agent behavior at a high level of abstraction better answer the case study challenge. This trade-off calls for a need for further exploration of the feedback mechanism specifically when pinpointing the factors that process-oriented SD loops can detect. Thereby the concept can be further explored concept to determine the effects of various driving forces that change the system over time. In this thesis, the interpretation capability of the SD feedback loop is incorporated in the added value feedback loop curve of the framework that generates new knowledge from concept unpacking and feeds it back to the system. This supports Forrester's view on the praxis of model adoption for generating insights rather than exact forecasts. However, from the PM perspective, "switching" the value of simulation modeling from concrete results that can be directly ascribed to the vagueness of "insights" bears certain risks of rejecting the approach. This means that even in cases where the expectations are clearly and timely communicated, the model may face rejection if decision-makers experience its results as disconnected from the practical utility of real-world problem-solving (Paper III). This implies that simulation modeling will inevitably experience a certain extent of tension between the utility of the model and the subjective experience of model stakeholders. Consequently, the question of resistance towards modeling should take the focus away from

model credibility and concentrate on the ways of improving the individual experiences that DM or other model users have with models. Naturally, only the practical utility does not define good research, as Hevner (2006) advocates for equal importance of relevance, rigor, and contribution. However, in this work, the practical utility has been put in the spotlight, which I consider acceptable since the research aims at increasing the adoption of digital practices.

6.3 The Regional Planning Perspective

As the evaluation of accessibility, which is one of the key components of quality of life and regional development, requires measures to prevent misinterpretations of policy effectiveness that can hinder successful regional development, the research is facing a need for a comprehensive holistic approach to this problem. While sustainability in regional development calls for the integration of spatial planning and institutional cooperation (Bjärstig et al. 2018), the absence of an established framework of such cooperation sets regional planning at risk. In Sweden, where there is no established framework for necessary cooperation in spatial planning, municipalities interpret their planning rights independently (Bergkvist Andersson & Schmitt, 2024). This autonomy often results in poor conformity with sustainability goals, and the already exposed rural areas become even more desolated due to population decline and socioeconomic inequality caused by inefficient and fragmented local planning. Therefore, this study on the one hand highlights the need for a knowledge-based approach, supporting cross-municipal regional planning, and on the other hand demonstrates the risks of segregated practices that are not tied to the needs and peculiarities of regional areas.

By focusing on the characteristics and function of regional accessibility, empirical data was gathered based on the feedback gained from communication with practitioners on several occasions that included participants from the case study region municipalities and group discussions with their representatives. Such interpretation and qualitative analysis allowed me to dive into the understanding of the problem and reoriented the

research from the evaluation of segregated accessibility indicators to the understanding of the roots of the problem and trying to develop a common ground for addressing it. This was done to ensure a holistic and comprehensive approach in the case where the ambiguity of the explored problem stirred the direction of the research towards understanding and interpreting the case study needs together with considering the discrepancy among the planners about what the explored complex notion entailed and how it could be approached.

The implemented model of regional accessibility was therefore based on empirical insights gained from the practitioners engaged in the field of planning for regional development. Zooming out from the model and the problem of accessibility to a bigger picture, the research highlights the need to address the root of the problem that lies in segregated regional planning and resistance to the adoption of contemporary digital practices that can support DM. Bergkvist Andersson and Schmitt (2024) admit that addressing the challenge of faltering regional planning is problematic considering the vagueness, generic nature of the problem, and multiplicity of possible approaches in regions. The authors indicate that at the same time the regions which initiated regionwide planning practices without waiting for legal requirements to abide them to do so, have experienced positive effects of this cooperation; moreover, in some cases, this initiative led to the formation of the legal framework. While the authors contemplate the pros and cons of legal mandates for such cooperation versus the freedom of choice in the absence of the requirements to abide by determined laws, the bottom-up approach of such initiative implies the advantage of such initiation for developing region-tied policies. This creates the preconditions for these areas to be addressed with regard to their specific needs, thus abiding the questionable advantage of "soft planning", which, among other drawbacks, is characterized by the lack of authority to enforce changes or possibilities to evaluate its influence on the welfare of regions and its population.

The simulation results of the region as a model of CAS reveal that the tendency of individuals to favor certain destinations can lead to significant variability in how destinations are utilized. The simulation underscores that

in regions where municipal centroids are developed separately, smaller communities may become isolated if planners do not consider the region-wide effects of destination distribution. This is justified by the emergent non-linear behavior of the ABM agents to favor popular destinations despite the availability of alternatives—leading to underutilization of less popular areas and potentially setting them at a higher risk of desolation than they are already experiencing.

The model demonstrates that, within a CAS, the balance between community size and destination availability is crucial. Destinations that initially attract a large number of visitors tend to continue to grow over time, whilst less popular destinations remain underutilized. This emerging pattern might result in competitive dynamics in which larger clusters outnumber smaller communities, aggravating intra-regional differences and competition.

The implications for planning underscore the importance of using a regional-scale strategy that considers the adaptive mechanisms that emerge within the system. Clustering tactics that overlook cross-municipal impacts might produce unsatisfactory results, as larger destination concentrations consume opportunities in smaller areas, leading to ever greater consequences on the socioeconomic challenges of the region. This is especially important in sparsely populated areas like the case study Sundsvall region in Sweden, where accessibility is essential for economic sustainability. These insights advocate for planning strategies that account for the system's adaptive nature, ensuring that municipalities can thrive by minimizing competition and fostering cooperative development. By zooming out once more to the perspectives of sparsely populated areas through the lens of the implications of the accessibility interpretation (from Paper II), these insights together with defining destinations as key descriptions of the regional accessibility concept, imply that regional areas require individual policymaking concerning destination development. This planning approach must ensure that each establishment, development, or relocation of regional destinations will be considered individually as to what effects such change may have on the whole region.

In conclusion, the research demonstrates that understanding regional accessibility via the lens of CAS can lead to an efficient knowledge-based planning approach. Planners can better handle the risks of unequal regional development by taking into account the emergent behaviors and interactions within the system. This enables to plan for sustainable development that takes account of common resources while protecting the region from poor allocation of scarce capabilities. Individual planning for destination development can ensure that the current state of the art in terms of regional needs is considered, and the risk of creating competition of opportunities that destabilize the regional image is minimized.

Due to the high level of abstraction and the need for an individual approach to planning for destinations, the implemented model is therefore useful for creating insights rather than serving as a daily decision support tool. From the perspective of PM, which in this thesis highlights the need to overcome the generic nature of simulation results and their implications, such an approach somewhat contradicts the requirements for diminishing resistance to modeling. However, by adhering to the social learning modeling purpose where illustrative capabilities of ABM to assist in developing a common vision, I pursue the goal of modeling, as a "scientific endeavor" that lies in building a "shared understanding that provides insight into the world and helps to solve important problems" (Sterman, 2000). This means that a digital practice in this context is utilized as a common platform that builds on the stakeholders' ideas by interpreting them via PM to develop a bigger picture that is often overlooked in praxis. The value of such an approach lies in supporting human decision-making rather than substituting it with exact policy and planning indications.

6.4 Handling Limitations

As any study is restricted to a certain area, method, or approach, this research is subject to certain limitations. Concerning the main contribution of suggesting a way to develop concrete variables for a dynamic simulation when modeling for complex concepts, the study advances the field of complex

systems, namely in interpreting and modeling for complex concepts that such systems deal with.

In terms of complex problems, the thesis explores the modeling of concepts that can be related to the domains of complex systems. Such concepts can be what is defined as wicked problems, or in general vague and fuzzy definitions that lack consensus on the common methods of their definition, evaluation, or application.

In terms of the adoption of simulation modeling, the thesis explores the resistance towards the adoption of dynamic simulation modeling methods of SD and ABM as they allow one to explore the system and its characteristics unfold over time. The simulation model was not considered as a stand-alone policy evaluation tool. Instead, it is viewed as a resource to support decision-makers at the policy design stage. This is done to improve the knowledge base and "help in the construction of actual explanations but do not constitute actual explanations themselves" (Grüne-Yanoff & Weirich, 2010). In other words, the work provides insights that contribute to a deeper understanding of the subject which should not be mistakenly accounted for generating a thorough explanation on its own. The simulation model consolidates the contributions from other papers and demonstrates the application of the developed research framework in practice.

In terms of cognitive decision-making, due to the high level of model abstraction, I do not consider possible influences from bounded rationality that often affect individuals in making decisions. Herbert Simon (1990) applied the concept of bounded rationality from decision-making and behavioral economics to explore how real-life decisions are made. The concept assumes that decision-making is limited to knowledge and cognitive abilities of an individual, often leading to satisfactory rather than optimal choices. Here, the assumption is that agents choose the option that generates the highest utility so that the "optimization in the sense of consumer utility and firm profit maximization are merely assumptions for a set of economic models that yield important and useful predictions" (Bettis & Hu, 2018).

In terms of the case study of the thesis, the thesis adopts ABM simulation methodology at a high level of abstraction to explore the major key associates of the complex regional accessibility concept and its main associates. This approach is considered liable given the problem of lack of institutional vision, thus, the high level of abstraction of the model, which explores the main regional planning approach of agglomeration, i.e., key dynamics of the regional accessibility system that are easier to communicate to stakeholders who are not specialists in simulation approaches. Approaching the problem this way allows to focus on the most critical components of a complex problem (which is the focus of the study) without overloading the model with a multiplicity of parameters, instead allowing generalizability of findings.

In terms of accessibility, the thesis views the concept in the context of regional development as it is understood by planners who work with it regularly, and the way they use it in their practice. The idea with this approach was not to redefine the notion or to "solve" the accessibility challenges (as some might expect, with varying interpretations of what "solving" entails) as a part of regional development by relying only on the model and its simulation results. As I investigated the notion and its interpretation in praxis as one of the factors that affect regional development, i.e., the concept was not addressed as a paradigm solely capable of shifting regional development. As the research journey advanced with collaborative activities through workshops and meetings with stakeholders, there were more background colors that were starting to come through the canvas of decision-making for regional development, such as the lack of consensus about the concept and methods of handling and evaluating it (therefore, the concept unpacking is tackled in the third study that deals with developing a better understanding of complex systems and concepts that such systems deal with). Since the preceding study had demonstrated the consequences of lack of agreement among regional planners as the latter would mainly plan based on the insights gained from a municipal level and own experience (which was highlighted by the implemented model), the focus of the research shifted. Instead of developing a "simple" evaluation artifact (model) to explore the paradox of segregated planning and its effects on a region as a conglomerate of municipal units, I found value in examining the practical value of adoption

modeling, as mentioned mainly due to the process of model design. This shift allowed to explore the concept that the model represents from another perspective as the old-fashioned approaches to the concept were not consistent with the contemporary challenges. Therefore, this research and its relation to the case study problem is in lieu of "… a conglomerate of different problems, and a piece of research may not attempt to address the whole conglomerate but may focus only on some specific subproblem" (Iivari, 2007).

In terms of the scope of PM deployment, scientific literature often uses PM and collaborative modeling interchangeably, though some research has drawn the line between the two based on the level of stakeholder involvement (Basco-Carrera et al., 2017). I restrict this discussion of PM adoption and do not elaborate on intensity of stakeholder involvement in this work. However, it is worth mentioning that their participation (or collaboration) is considered in a broader context, such as guidance of the five basic principles of the developed framework. As the framework is not a specific hard-wired methodology, but a general approach, it may require varying levels of stakeholder engagement depending on the objective of a specific study that applies the framework. In this specific research, the engagement was mainly considered in the following aspects: understanding the problem (pre-modeling), developing concrete variables based on stakeholders' views (model development stage), and discussing the model implications with the stakeholders (model evaluation). However, developing the cooperation framework in advance before modeling and communicating it to the stakeholders may be an effective tool for certain contexts, given that tight communication is one of the key agreements between the parties and is the preferred research approach.

6.5 Future Research

Alongside the advantages of the developed framework, its flexibility highlighted potential future aspects that need to be addressed next. As the framework "splits" the top concept into its constituent parts, depending on which method a researcher uses to extract those components, some of them

may overlap or contradict. This can become more obvious at the higher number of the unpacking loop iterations unless all the preceding components are considered together to ensure there is no duplication, contradiction, or overlap. Another reason for the need to review the top concepts and each of their splits even if the researcher is currently in a parallel "branch" of the concept split is to ensure that the gap between the components is not expanded. This means that the compounds should not become so distant that the top concept starts to lose the meaning of the umbrella that unites them, and therefore may require to be filled with more information due to the increasing volume of the empty spaces between the compounds. Figure 7 demonstrates the extraction processes in case of several iterations illustrating an example of how a potential partial overlap of the components in parallel "branches" could happen if, for example, two of the elements were split into the same compound, and the modeler would have to deal with the problem of eliminating the duplicate.

These developments are important for the research that deals with implications of complexity on modeling and model design, specifically in cases where the framework is not only used to better understand the top

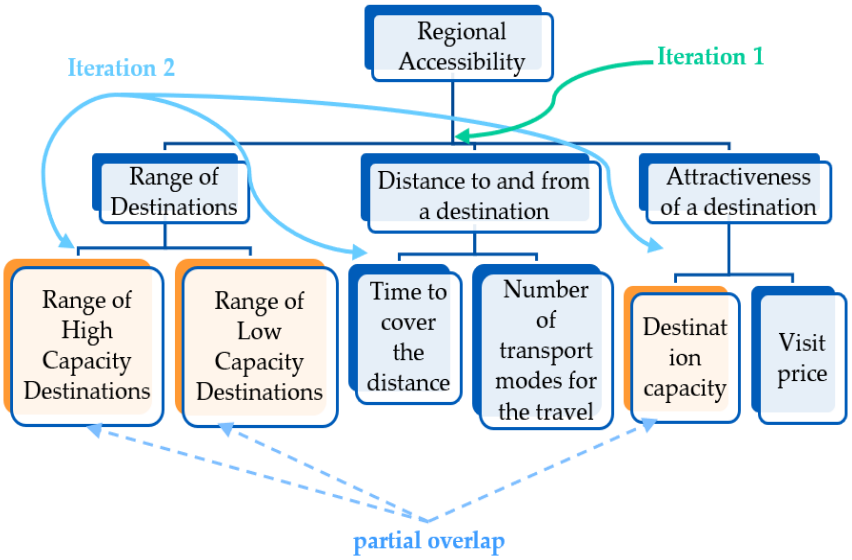

Figure 7: Potential shortcomings of the complex concept unpacking framework

concept but also to extract variables for the consequent modeling. The reason for considering these developments is to enable the comprehensive approach that does not disregard the complex and often multifaceted nature of a concept, phenomenon, or problem, as the researcher's primal interest lies in improving the interpretation and consequent treatment of the top concept, not in finding the ways to substitute it with "smaller" notions. This way, the developed framework would ensure that the system or concept in question is indeed explored "as a whole", and that the complex elements, interactions, or processes that the research deals with do not get neglected, risking being deemed a reductionist approach (Minati, 2024). This implies that these risks may be higher as the number of framework loop iterations increases, and their continuous conformity with the representativeness of the top concepts needs to be constantly monitored during the iterations.

Concerning regional planning, the developed accessibility model could be expanded with SD loops to pinpoint the processes of the system that have the greatest influence on its dynamic, implying a somewhat lower level of model abstraction. The analyses of such a model may engage decision-makers in a constructive discourse that considers the implications of the importance and prevailing influence of certain parts of the system, that may otherwise have been overlooked.

7 Concluding Remarks

This research explored the potential of complexity in addressing challenges of sustainable regional development of Sundsvall's region of Sweden. By incorporating planners' vision, it developed a research framework aimed at reducing resistance to simulation and enriching the knowledge about the system in question. The framework stirred the development of a simulation model that explored the dynamics in the regional accessibility system to support DM with insights for knowledge-based long-term planning for regional development. This approach highlighted the value of model design in knowledge creation.

The findings related to the RQs can be concluded as follows:

RQ 1) How can the complexity of accessibility and its evaluation be addressed in sustainable regional planning?

The question concerning the problem of approaching accessibility and incorporating it in regional planning stems from the lack of a complex system perspective and unified institutional approach. This hinders the adoption of digital practices that have the advantage of assisting in the realm of complexity by facilitating our understanding of a complex concept and its main constituents. Complex adaptive systems facilitate the development of a unified vision and abandonment of inefficient linear approaches based on restricted mental models and personal experiences as the main components of planning.

RQ 2) How can the perspective of complex systems and concepts facilitate the adoption of simulation modeling as a digital practice in decision-making?

Addressing the development of simulation models shows the gap in defining variables. In the realm of complex problems, it means that as a model reflects the real-world system, the design of key parameters of such a model must be clearly defined. Such a concept in he case of dealing with complex systems, as in this thesis, can be understood and modeled by splitting the

concept into its key associated interpretations that are less abstract than the top concept.

In the scientific community, researchers typically begin modeling by choosing theories that they want to base a model on. The toolset of switching from a theory to a concrete model is very restricted and is mainly covered by general guiding principles that theories of simulation modeling and participatory modeling provide. However, these principles do not tell model designers what is alpha and omega for their model design - the key model parameters or variables that build up a model. By applying the developed framework based on participatory modeling, I engage stakeholders (in this thesis: decision-makers) in the process of deconstructing the phenomenon that is to be modeled and use the deconstruction results as a set of key variables that serve as the alpha and omega for a model buildup. This approach suggests concrete steps to design a model based on the existing knowledge about the phenomenon and ensures that the model is grounded in real-world insights and the stakeholders' perspectives.

To sum up, the reason for designing and deploying the research framework is two-fold: model design and development of the implemented model based on the framework application assists regional planning for the case study of this thesis, and it enhances the adoption of digital practices, namely, simulation modeling, to deals with concepts within the domains of complex systems.

Bibliography

Addis, T.R., & Gooding, D.C. (2008). Simulation methods for an abductive system in science. *Foundations of Science, 13*(1), 37–52. https://doi.org/10.1007/s10699-007-9113-8

Adolphson, M., & Jonsson, D. (2020.) Uncover the theory practice gap in Swedish transport planning: an interdisciplinary approach. *European Planning Studies, 28* (11), 2237–2260. https://doi.org/10.1080/09654313.2020.1715927

Allen, P. (1995). Cities and regions as evolutionary complex systems. *Journal of Geographical Systems, 4*(1), 103–130.

Asimov, I. (1989). The relativity of wrong. *The Skeptical Inquirer, 14*(1), 35-44.

Azizinezhad, M., & Hashemi, M. (2011). Technology as a medium for applying constructivist teaching methods and inspiring kids. *Procedia - Social and Behavioral Sciences, 28*, 862–866. https://doi.org/10.1016/j.sbspro.2011.11.158

Bansler, J. P. (1989). Systems development research in Scandinavia: Three theoretical schools. *Scandinavian Journal of Information Systems, 1*(1), 1-14.

Bartels, W.-L., & Furman, C. A. (2023). Building community for participatory modeling: Network composition, trust, and adaptive process design. *Society & Natural Resources, 36*(3), 326–346. https://doi.org/10.1080/08941920.2023.2177916.

Basco-Carrera, L., Warren, A., van Beek, E., Jonoski, A., & Giardino, A. (2017). Collaborative modelling or participatory modelling? A framework for water resources management. *Environmental Modelling & Software, 91*, 95–110. https://doi.org/10.1016/j.envsoft.2017.01.014.

Belfrage, M., Lorig, F., & Davidsson, P. (2022). Making sense of collaborative challenges in agent-based modelling for policy-making. In *Proceedings of the 2nd Workshop on Agent-Based Modeling and Policy-Making (AMPM 2022).* Presented at *Saarbrücken, Germany, December 14, 2022*. Retrieved from https://urn.kb.se/resolve?urn=urn:nbn:se:mau:diva-66202.

Benbasat, I., Goldstein, D. K., & Mead, M. (1987). The case research strategy in studies of information systems. *MIS Quarterly, 11*(3), 369–386. https://doi.org/10.2307/248684.

Bergkvist Andersson, H., & Schmitt, P. (2024). Disclosing the logics of non-statutory regional planning: The case of Sweden. *European Planning Studies, 32*(8), 1793–1812. https://doi.org/10.1080/09654313.2024.2337308

Box, G. E. P. (1976). Science and statistics. *Journal of the American Statistical Association, 71*(356), 791–799. https://doi.org/10.2307/2286841

Bettis, R., & Hu, S. (2018). Bounded rationality, heuristics, computational complexity, and artificial intelligence. In *Advances in Strategic Management* (pp. 139–150). https://doi.org/10.1108/S0742-332220180000039010

Bjärstig, T., Thellbro, C., Stjernström, O., Svensson, J., Sandström, C., Sandström, P., & Zachrisson, A. (2018). Between protocol and reality – Swedish municipal comprehensive planning. *European Planning Studies, 26*(1), 35–54. https://doi.org/10.1080/09654313.2017.1365819

Borshchev, A. (2013). *The big book of simulation modeling: Multimethod modeling with Anylogic 6*. Anylogic North America.

Braun, V., Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101. https://doi.org/10.1191/1478088706qp063oa

Brendel, A. B., Chasin, F., Mirbabaie, M., Riehle, D. M., & Harnischmacher, C. (2022). Review of design-oriented green information systems research. *Sustainability, 14*(8), Article 8. https://doi.org/10.3390/su14084650

Brinkmann, S. (2020). Unstructured and semistructured interviewing. In P. L. (Ed.), *The Oxford Handbook of Qualitative Research: Second Edition* (2 ed., pp. 424-456). Oxford University Press. https://doi.org/10.1093/oxfordhb/9780190847388.013.22

Burian, J., Stachova, M., & Vondrakova, A. (2018). Land suitability assessment of the Olomouc region: An application of an Urban Planner model. *Journal of Maps, 14*(1), 73–80. https://doi.org/10.1080/17445647.2018.1493407

Burton, R., & Obel, B. (1995). The validity of computational models in organization science: From model realism to purpose of the model. *Computational and mathematical organization theory, 1*(1), 57-71.

Buzási, A., & Csete, M. (2015). Sustainability indicators in assessing urban transport systems. *Periodica Polytechnica Transportation Engineering, 43*(3), Article 3. https://doi.org/10.3311/PPtr.7825

Combes, P.-P., & Gobillon, L. (2015). Chapter 5—The Empirics of Agglomeration Economies. In G. Duranton, J. V. Henderson, & W. C. Strange (Eds.), *Handbook of Regional and Urban Economics* (Vol. 5, pp. 247–348). Elsevier. https://doi.org/10.1016/B978-0-444-59517-1.00005-2

Creswell, J. W. (2014). *Research design: qualitative, quantitative, and mixed methods approaches* (Fourth edition, international student edition.). SAGE, pp. 77-104.

deMattos, P., Miller, D., & Park, E. (2012). Decision making in trauma centers from the standpoint of complex adaptive systems. *Management Decision, 50*. https://doi.org/10.1108/00251741211266688

Durán, J.M. (2020). What is a simulation Model? *Minds & Machines* 30, 301–323.

https://doi.org/10.1007/s11023-020-09520-z

Durán, J.M. (2021). A Formal Framework for Computer Simulations: Surveying the Historical Record and Finding Their Philosophical Roots. *Philosophy & Technology*, 34, 105–127. https://doi.org/10.1007/s13347-019-00388-1

Dörner D., & Funke J. (2017.) Complex problem solving: What it is and what it is not. *Frontiers in Psychology*, *8*, 1153. https://doi.org/10.3389/fpsyg.2017.01153

Eldabi, T., Irani, Z., & Paul, R. (2002). Quantitative and qualitative decision-making methods in simulation modeling. *Management Decision*, *40*(1), 64–73. https://doi.org/10.1108/00251740210413370

Estrada, E. (2023). What is a complex system, after all? *Foundations of Science*. https://doi.org/10.1007/s10699-023-09917-w

Ethics in research and good research practice. (2019, January 10). [Text]. *Swedish Research Council*. https://www.vr.se/english/mandates/ethics/ethics-in-research.html

European Commission. (2015, November 10). *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions. EU Enlargement Strategy. COM (2015) 611 Final*. Brussels. https://neighbourhood-enlargement.ec.europa.eu/document/download/1239c42a-64a9-4516-b9b6-63d673344ae1_en?filename=20151110_strategy_paper_en.pdf

Flensburg, P. (2017). Becoming professor: With almost no publications. *Scandinavian Journal of Information Systems, 29*(1), 135–160.

Forrester, J. W. (1961). *Industrial dynamics*. MIT Press: Cambridge, Massachusetts.

Forrester, J.W. (1971). *Principles of systems: Text and Workbook*. Cambridge, Wright-Allen Press.

Forrester, J.W. (2009). *Some basic concepts in system dynamics.* Sloan School of Management, Massachusetts Institute of Technology, Cambridge, MA.

Freebody, P. (2002). *Qualitative research in education: Interaction and practice (pp. 74-89)*. Thousand Oaks, CA: Sage Publications.

Gallent, N., & Gkartzios, M. (2019). Defining rurality and the scope of rural planning. In *Rural planning and development* (pp. 17–27). https://doi.org/10.4324/9781315102375-3

Geurs, K. T., & van Wee, B. (2004). Accessibility evaluation of land-use and transport strategies: Review and research directions. *Journal of Transport Geography*, *12*(2), 127–140. https://doi.org/10.1016/j.jtrangeo.2003.10.005.

Gilbert, N., Ahrweiler, P., Barbrook-Johnson, P., Narasimhan, K. P., & Wilkinson, H. (2018). Computational modelling of public policy: Reflections on practice. *Journal of Artificial Societies and Social Simulation, 21*(1), 14. https://www.jasss.org/21/1/14.html

Gilbert, N., & Troitzsch, K. G. (2015.) *Simulation for the social scientist* (2nd ed.) Open University Press, Berkshire, UK.

Gill, I. S., & Goh, C.-C. (2010). Scale economies and cities. *The World Bank Research Observer, 25*(2), 235–262. https://doi.org/10.1093/wbro/lkp022

Godfrey-Smith, P. (2003). *Theory and reality: an introduction to the philosophy of science*. University of Chicago Press.

Gorecki, S., Zerguini, S., Gaussier, N., & Traoré, M. (2023). Multisectoral household location agent-based simulation for testing policy decisions. In G. Ježić, J. Chen-Burger, M. Kusek, R. Sperka, R. J. Howlett, & L. C. Jain (Eds.), *Agents and multi-agent systems: Technologies and applications* 2023 (pp. 87–98). Springer Nature. https://doi.org/10.1007/978-981-99-3068-5_8

Grimm, V., Berger, U., Bastiansen, F., Eliassen, S., Ginot, V., Giske, J., Goss-Custard, J., Grand, T., Heinz, S. K., Huse, G., Huth, A., Jepsen, J. U., Jørgensen, C., Mooij, W. M., Müller, B., Pe'er, G., Piou, C., Railsback, S. F., Robbins, A. M., … DeAngelis, D. L. (2006). A standard protocol for describing individual-based and agent-based models. *Ecological Modelling, 198*(1), 115–126. https://doi.org/10.1016/j.ecolmodel.2006.04.023

Grimm, V., Railsback, S. F., Vincenot E. C., Berger, U., Gallagher, C., DeAngelis, D. L. Edmonds, B., et al. (2020). "The ODD protocol for describing agent-based and other simulation models: A second update to improve clarity, replication, and structural realism." *Journal of Artificial Societies and Social Simulation, 23* (2), 7. http://jasss.soc.surrey.ac.uk/23/2/7.html

Große, C. (2022). Towards a holistic perspective on future transportation systems: A Swedish case and a conceptual Framework. *Future Transportation, 2*(4), Article 4. https://doi.org/10.3390/futuretransp2040047

Große, C., & Olausson, P. (2019). Blind spots in interaction between actors in Swedish planning for critical infrastructure protection. *Safety Science*, *118*, 424–434. https://doi.org/10.1016/j.ssci.2019.05.049

Grundel, I., & Magnusson, D. (2022.) Planning to grow, planning to rock on – infrastructure management and development in shrinking municipalities, *European Planning Studies*. https://doi.org/10.1080/09654313.2022.2108311

Grune-Yanoff, T., & Weirich, P. (2010). The philosophy and epistemology of simulation: A review. *Simulation & Gaming, 41*, 20-50. https://doi.org/10.1177/1046878109353470

Guba, E. G. (1990). *The Paradigm Dialog*. Sage Publications.

Hansen, W. G. (1959). How accessibility shapes land use. *Journal of the American Institute of Planners, 25*(2), 73–76. https://doi.org/10.1080/01944365908978307

Hegselmann, R. (2012). Thomas C. Schelling and the computer: Some notes on Schelling's Essay "On Letting a Computer Help with the Work". *Journal of Artificial Societies and Social Simulation, 15*(4), 9.

Held, F., Wilkinson, I. F., Marks, R., & Young, L. (2014). Agent-based modelling, a new kind of research. *Australasian Marketing Journal, 22*(1), 4–14.

Hevner, A. (2007). A Three Cycle View of Design Science Research. *Scandinavian Journal of Information Systems, 19*.

Holl, A., & Maydt, D. (2007). Epistemological foundations of requirements engineering. In A. Erkollar (Ed.), *Enterprise and business management: A handbook for educators, consulters and practitioners*, (pp. 31-58). Marburg: Tectum.

Holland, J.H. (2006.) Studying complex adaptive systems. *Journal of Systems Science and Complexity, 19*, 1–8. https://doi.org/10.1007/s11424-006-0001-z

Hollander, J. B. (2018). *A research agenda for shrinking cities.* Cheltenham/Northhampton, MA: Edward Elgar.

Iivari, J. (2007). A paradigmatic analysis of information systems as a design science. *Scandinavian Journal of Information Systems, 19(*2), Article 5. Available at: https://aisel.aisnet.org/sjis/vol19/iss2/5

Jamei, E., Chan, M., Chau, H. W., Gaisie, E., & Lättman, K. (2022). Perceived accessibility and key influencing factors in transportation. *Sustainability, 14*(17), 10806. MDPI AG. Retrieved from http://dx.doi.org/10.3390/su141710806

Kayande, U., De Bruyn, A., Lilien, G., Rangaswamy, A., & Bruggen, G. (2009.) How incorporating feedback mechanisms in a DSS affects DSS evaluations. *Information Systems Research, 20*(4): 527-546.

Kelly (Letcher), R. A., Jakeman, A. J., Barreteau, O., Borsuk, M. E., ElSawah, S., Hamilton, S. H., Henriksen, H. J., Kuikka, S., Maier, H. R., Rizzoli, A. E., van Delden, H., & Voinov, A. A. (2013). Selecting among five common modelling approaches for integrated environmental assessment and management. *Environmental Modelling & Software, 47*, 159–181. https://doi.org/10.1016/j.envsoft.2013.05.005

Kimmich, C., Gallagher, L., Kopainsky, B., Dubois, M., Sovann, C., Buth, C., & Bréthaut, C. (2019). Participatory modeling updates expectations for individuals and groups, catalyzing behavior change and collective action in water-energy-food nexus governance. *Earth's Future, 7*(12), 1337–1352.

https://doi.org/10.1029/2019EF001311

Kin, W., & Chan, V. (2011). Foundations of simulation modeling. In *Wiley Encyclopedia of Operations Research and Management Science*. John Wiley & Sons, Ltd. https://doi.org/10.1002/9780470400531.eorms0336

Kotavaara, O., Pukkinen, M., Antikainen, H., & Rusanen, J. (2014). Role of accessibility and socio-economic variables in modelling population change at varying Scale. *Journal of Geographic Information System, 6*(4), Article 4. https://doi.org/10.4236/jgis.2014.64034

Ladyman, J., Lambert, J., & Wiesner, K. (2013). What is a complex system? *European Journal for Philosophy of Science, 3*, 33–67.

Larsson, A., Elldér, E., Vafeiadis, E., Curtis, C., & Steiner, A. (2022.) Exploring the potential for sustainable accessibility across settlement types: A Swedish case. *Transportation Research Part D: Transport and Environment, 107*, 103297. https://doi.org/10.1016/j.trd.2022.103297

Lavesson, N. (2017). *Rural-urban interdependencies: The role of cities in rural growth.* [Doctoral Thesis (compilation), Department of Human Geography]. Lund University.

Law, A. M. (2007). *Simulation modeling and analysis* (4th Edition). McGraw-Hill.

Law, A. M. (2015). *Simulation Modeling and Analysis* (5th Edition). McGraw-Hill.

Lawlor, J. A., & McGirr, S. (2017). Agent-based modeling as a tool for program design and evaluation. *Evaluation and Program Planning, 65*, 131–138. https://doi.org/10.1016/j.evalprogplan.2017.08.015

López, E., Gutiérrez, J., & Gómez, G. (2008). Measuring regional cohesion effects of large-scale transport infrastructure investments: An accessibility approach. *European Planning Studies, 16*(2), 277–301. https://doi.org/10.1080/09654310701814629.

Lättman, K., Olsson, L. E., & Friman, M. (2018). A new approach to accessibility – Examining perceived accessibility in contrast to objectively measured accessibility in daily travel. *Research in Transportation Economics*, *69*, 501–511.

Maksimović, J., & Evtimov, J. (2023). Positivism and post-positivism as the basis of quantitative research in pedagogy. *Research in Pedagogy, 13*, 208-218. https://doi.org/10.5937/IstrPed2301208M

McCann, P., & van Oort, F. (2019). Chapter 1: Theories of agglomeration and regional economic growth: A historical review. In *Handbook of regional growth and development theories*. Edward Elgar.

https://www.elgaronline.com/edcollchap/edcoll/9781788970013/9781788970013.00007.xml

Minati, G. (2024). Theoretical reflections on reductionism and systemic research issues: Dark systems and systemic domains. *Systems*, *12*(1), Article 1. https://doi.org/10.3390/systems12010002

Modell, S. (2009). In defence of triangulation: A critical realist approach to mixed methods research in management accounting. Management Accounting Research, 20(3), 208–221. https://doi.org/10.1016/j.mar.2009.04.001

Morris, J.M., Dumble, P.L., & Wigan, M.R. (1979) Accessibility indicators for transport planning. *Transportation Research Part A: General, 13*, 91-109. Retrieved August 12, 2024, from https://www.scirp.org/reference/referencespapers?referenceid=3402010

Munn, Z., Peters, M. D. J., Stern, C., Tufanaru, C., McArthur, A., & Aromataris, E. (2018). Systematic review or scoping review? Guidance for authors when choosing between a systematic or scoping review approach. *BMC Medical Research Methodology*, *18*(1), 143. https://doi.org/10.1186/s12874-018-0611-x

Niloofar, P., Francis, D. P., Lazarova-Molnar, S., Vulpe, A., Vochin, M.-C., Suciu, G., Balanescu, M., Anestis, V., & Bartzanas, T. (2021). Data-driven decision support in livestock farming for improved animal health, welfare and greenhouse gas emissions: Overview and challenges. *Computers and Electronics in Agriculture*, *190*, 106406. https://doi.org/10.1016/j.compag.2021.106406

Oates, B. J., Oates, B. J., Griffiths, M., & McLean, R. (2022). *Researching information systems and computing* (2nd ed.). SAGE, 114-115.

Park, Y. S. Konge, L., & Artino, A. (2019). The Positivism Paradigm of Research. *Academic Medicine*, *95*(1), 1. https://doi.org/10.1097/ACM.0000000000003093

Pfaffenbichler, P., Emberger, G., & Shepherd, S. (2008). The integrated dynamic land use and transport model MARS. *Networks and Spatial Economics*, *8*(2), 183–200. https://doi.org/10.1007/s11067-007-9050-7

Preston, J., & Rajé, F. (2007). Accessibility, mobility and transport-related social exclusion. *Journal of Transport Geography*, *15*(3), 151–160. https://doi.org/10.1016/j.jtrangeo.2006.05.002

Quimby, B., & Beresford, M. (2023). Participatory modeling: A methodology for engaging stakeholder knowledge and participation in social science research. *Field Methods*, *35*(1), 73-82. https://doi.org/10.1177/1525822X221076986

Railsback F. S., & Grimm V. (2019). *Agent-based and individual-based modeling: A practical introduction* (2nd ed.). Princeton University Press, pp. 249-262.

Rand, W., & Rust, R. T. (2011). Agent-based modeling in marketing: Guidelines for rigor (SSRN Scholarly Paper 1818543). https://papers.ssrn.com/abstract=1818543

Rasca, S., & Høgli Major, J. (2021). Applicability of existing public transport sustainability indicators to Norwegian small cities and towns. *2021 Smart City Symposium Prague (SCSP)*, 1–6. https://doi.org/10.1109/SCSP52043.2021.9447387

Rojas, R., Castilla-Rho, J., Bennison, G., Bridgart, R., Prats, C., & Claro, E. (2022). Participatory and integrated modelling under contentious water use in semiarid basins. *Hydrology, 9*(3), Article 3. https://doi.org/10.3390/hydrology9030049

Rotoli, F., Elena, N., & Christidis, P. (2015). A data envelopment analysis approach for accessibility measures: Simulating operational enhancement scenarios for railway across Europe. *European Transport Research Review, 7*. https://doi.org/10.1007/s12544-015-0167-3

Rowe, F. (2014). What literature review is not: Diversity, boundaries and recommendations. *European Journal of Information Systems, 23*, 241–255. https://doi.org/10.1057/ejis.2014.7

Ryan, A. (2008). What is a systems approach? Available at: http://arxiv.org/pdf/0809.1698.pdf (last accessed 17 March 2024).

Ryan, J., Martens, K. (2023). Defining and implementing a sufficient level of accessibility: What's stopping us? *Transportation Research Part A: Policy and Practice, 175*, 103792. https://doi.org/10.1016/j.tra.2023.103792

Rybski, D., & González, M. C. (2022). Cities as complex systems—Collection overview. *PLOS ONE, 17*(2), e0262964. https://doi.org/10.1371/journal.pone.0262964

Saif, M. A., Zefreh, M. M., & Torok, A. (2019). Public transport accessibility: A literature review. *Periodica Polytechnica Transportation Engineering, 47*(1), Article 1. https://doi.org/10.3311/PPtr.12072

SALAR (2023). Swedish Association of Local Authorities and Regions. Retrieved October 31, 2024, from https://skr.se/en/skr/tjanster/kommunerochregioner/faktakommunerochregioner/kommungruppsindelning.2051.html

Sandberg, K., & Petersen, T. (2024). ABC om tillgänglighet. *Transportstyrelsen*. Retrieved November 1, 2024, from https://www.trafa.se/etiketter/transportovergripande/abc-om-tillganglighet-14864/

Shannon, R. E. (1998). Introduction to the art and science of simulation. In *Proceedings of the 1998 Winter Simulation Conference* (pp. 7-14). IEEE. https://doi.org/10.1109/WSC.1998.744892

Simon, H. A. (1990). Bounded Rationality. In J. Eatwell, M. Milgate, & P. Newman (Eds.), *Utility and Probability* (pp. 15–18). Palgrave Macmillan UK. https://doi.org/10.1007/978-1-349-20568-4_5

Sjöberg, I. (2023). From social engineering to neoliberal governance, and then what? Mapping a sustainability shift in urban planning in a medium-sized Swedish city. *Frontiers in Sustainable Cities, 5*. https://doi.org/10.3389/frsc.2023.1273972

SOU – Statens Offentliga Utredningar. (2015, June 15). En ny regional planering – ökad samordning och bättre bostadsförsörjning. *SOU 2015:59*, Stockholm. Regeringskansliet; Regeringen och Regeringskansliet. Retrieved from https://www.regeringen.se/rattsliga-dokument/statens-offentliga-utredningar/2015/06/sou-201559/

Sterman, J. D. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World*. Irwin/McGraw-Hill.

Sun, L., Chen, J., Li, Q., & Huang, D. (2020). Dramatic uneven urbanization of large cities throughout the world in recent decades. *Nature Communications*, *11*, 5366. https://doi.org/10.1038/s41467-020-19158-1

Tebelius, U., & Patel, R. (1987). *Grundbok i forskningsmetodik: kvalitativt och kvantitativt.* Studentlitteratur, p. 16.

Teixeira, P., Eusébio, C., & Teixeira, L. (2024). Understanding the integration of accessibility requirements in the development process of information systems: A systematic literature review. *Requirements Engineering, 29*, 1–34. https://doi.org/10.1007/s00766-023-00409-8

Turner, J., & Baker, R. (2019). Complexity theory: An overview with potential applications for the social sciences. *Systems, 7*. https://doi.org/10.3390/systems7010004

Wiggins, S., & Proctor, S. (2001). How special are rural areas? The economic implications of location for rural development. *Development Policy Review, 19*(4), 427–436. https://doi.org/10.1111/1467-7679.00142

Wilensky, U., & Rand, W. (2007). Making models match: Replicating an agent-based model. *Journal of Artificial Societies and Social Simulation, 10*(4), 2. https://www.jasss.org/10/4/2.html

Wilensky, U., & Rand, W. (2015). *An Introduction to agent-based modeling: modeling natural, social, and engineered complex systems with NetLogo*. The MIT Press. http://www.jstor.org/stable/j.ctt17kk851

Ximénez-De-Embún, D. P., & Sanso, M. (2011). Urban agglomeration and the aggregate economic growth. *Econstor*. https://www.econstor.eu/handle/10419/120146

Yilmaz, K. (2013). Comparison of quantitative and qualitative research traditions: Epistemological, theoretical, and methodological differences. *European Journal of Education*, *48*(2), 311-325. https://doi.org/10.1111/ejed.12014

Zachrisson, A., Bjärstig, T., Thellbro, C., Neumann, W., & Svensson, J. (2021.) Participatory comprehensive planning to handle competing land-use priorities in the sparsely populated rural context. *Journal of Rural Studies, 88*, 1-13. https://doi.org/10.1016/j.jrurstud.2021.09.031

Zykiene I., Snieska V., Bruneckiene J., & Burksaitiene D. (2021.) Assessment of regions using an index for a location's attractiveness for business development. *Economic Research-Ekonomska Istraživanja, 34*(1), 1366-1384. https://doi.org/10.1080/1331677X.2020.1825106

Österle, H., Becker, J., Frank, U., Hess, T., Karagiannis, D., Krcmar, H., Loos, P., Mertens, P., Oberweis, A., & Sinz, E. (2011). Memorandum on design-oriented information systems research. *European Journal of Information Systems, 20*(20), 7-10.