



# From Systems to Patterns and Back

Exploring the spatial role of dynamic time  
and direction patterns in the area of  
regional planning

The case of the Arctic Ocean Railway

| *Master thesis* |

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2020

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Title: **"From Systems to Patterns and Back —  
Exploring the spatial role of the dynamic time and direction patterns in the area of regional planning"**

Department: Department of Architecture

Program: M.Sc. in Architecture

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Year: 2020

Language: English

Pages: 145

All images are created by the author if not marked otherwise.



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and Architecture**



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**Title of thesis** From Systems to Patterns and Back- Exploring the spatial potential of dynamic time and direction patterns in the area of regional planning

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**Department** Department of Architecture

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**Degree programme** M.Sc. of Architecture

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**Year** 2020

**Number of pages** 145

**Language** English

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### Abstract

This master thesis presents a data-driven framework to explore the role of dynamic time and direction patterns in the area of Finnish Lapland in order to improve decision-making in urban planning and design tasks. The Arctic Ocean Railway project is chosen as a case study.

In an era marked by dramatic environmental, political and societal changes, the Arctic region becomes more global and complex. An increasing number of actors are involved in its spatial transformations. Due to melting ice, the Northern Sea Route gains attention from the shipping and trade industries that are manifested in new port and infrastructure projects. Eco-tourism is booming in the Arctic due to its imaginary remoteness, while local Indigenous People try to preserve traditional livelihoods.

In order to cope with the increasing complexity of such dynamic urban and regional challenges, Systems Thinking, dynamic patterns, modelling and use of simulation are researched to open up novel ways for complex regional planning methods.

This is achieved by designing an agent-based model and using different representation and abstraction features for different dynamic data packages. The project is integrated within the GAMA simulation platform (a modeling and simulation development environment for building spatially explicit agent-based simulations) and embedded in the MIT CityScope framework - a medium for both, analyzing agent's behavioral patterns and displaying them to the relevant stakeholders.

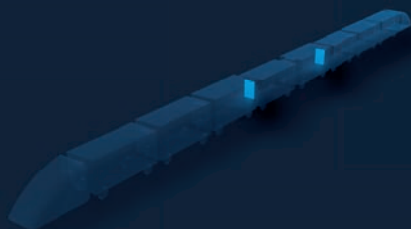
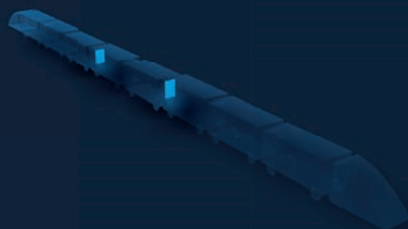
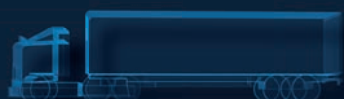
The project attempts to address the necessity to handle the increasing complexity by presenting a dynamic, evidence-based planning and decision support tool called CityScope Lapland. The main goal of CityScope Lapland is to use digital technologies to incorporate variables like time and direction in urban spatial analysis and methodology; secondly, to improve the accessibility of the decision-making process for non-experts through a tangible user interface, and third, to help users evaluate their decisions by creating a feedback through real-time visualization of urban simulation results when facing less and less predictable futures.

The project provides an alternative design approach, introducing new forms of urban imagination and different ways of perceiving and measuring complex spatial transformations.

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**Keywords** Systems Thinking, simulation, agent-based modelling, patterns, Arctic Ocean Railway, decision support tools

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# PART I

## Research

*PART I presents the thesis' theoretical framework. The existing background research on the topic and relevant theories are discussed in this section in order to introduce the chosen problem.*

*The author examines the on-going spatial transformations and challenges shared across the Arctic countries. The concept of spatial narratives is introduced and later used to structure the complexity of different Arctic phenomena.*

*The use of a case study — the Arctic Ocean Railway — helps to visualise how the complex challenges manifests within the same project.*

*PART I evaluates the potential use of the Systems Thinking approach and dynamic patterns in planning processes. This section further describes a selection of spatial narratives with occurring dynamic patterns in Finnish Lapland that are either existing or speculative.*

*The goal of PART I is to land the reader in a specific place and time. By using Systems Thinking and dynamic patterns, it further points out what to look for when dealing with planning challenges in complex systems like Finnish Lapland.*

*In the beginning, the reader is presented with the thesis topic, research question, problem and the other aspects of this work.*

# Chapter 1

## *Intro*

*Within the introduction chapter the reader is guided into the thesis topic. The research questions are discussed, as well as the other necessary aspects of the thesis. The main purpose of this chapter is to give an introduction into the structure:*

- *Thesis' subject topic*
- *Research question*
- *Problem statement*
- *Obectives*
- *Background*
- *Methodology*
- *Scope & challenges*
- *Use of the study and possible audience*

# 1. Introduction

## 1.1. Subject topic & reserach question

The planning and design discipline is facing new dynamic and complex challenges, requiring a re-thinking of traditional planning tools and methods. In order to tackle this emerging complexity, an exploration for a more suitable paradigm is needed.

One example, where failing to address these complex planning challenges might cause prominent consequences, not only for the locals living there but also for the global community, is the Arctic region and its states. Because of the magnitude and relationships of these challenges, Finnish Lapland and the potential Arctic Ocean Railway project are chosen as a case study. However, similar projects take place across the region and, therefore, it is worth investigating how new planning tools and methods could be applied to a range of cases.

Multiple spatial narratives exist in the Arctic region: as a homeland, a source of resources or a crucial part in the climate regulation system (Arctic Council, 2016). Alongside with existing narratives, new speculative ones emerge, e.g. shipping, infrastructure or energy. They exist throughout the Arctic states, including Finland.

Separating these narratives is a common practice to understand and manage the on-going spatial transformations. Each of them is accompanied by different strategies for creating the necessary built environment. However, by separating these narratives, a lot of correlation and interconnections can be lost. As a result, it limits the impact of planning actions.

In the current context of global warming, accelerating complexity and dynamics, spatial narratives become more connected and interdependent. Existing correlations between them often form patterns that are difficult to notice but important in spatial analysis. Therefore, these narratives require immediate attention, employing more suitable theoretical frameworks and strategies like Systems Thinking and dynamic patterns.

Karen M'Closkey and Keith VanDerSys define patterns as "[...] relational frameworks that simultaneously describe and project; they reveal structures, processes, and relationships, as well as physical structure frameworks that give shape and form to our world" in their book "Dynamic Patterns"(2017). The focus of this work lays on dynamic patterns as a potential source for new ways to analyse and understand the complexity of the on-going spatial transformations and proposes an alternative method.

**The research question that this work attempts to answer is "How can time and direction patterns be used in planning methodology as tools to conceptualise the complex system of Finnish Lapland and support decision-making process in planning and design tasks?"**



## 1.2. Problem statement

To better understand existing spatial complexity in the urban planning and design field of the Finnish Lapland, stakeholders need tools and methods that address the internal correlations between different spatial narratives in the region. For example, they can be analysed through occurring time and direction patterns. Currently, no decision support tool addresses and quantifies concepts such as agent directionality and its impact on the Arctic urban development; or the role of time patterns in possible conflict situations among different agents. The role and impact of these patterns on spatial transformations are only studied on a general level but not used in the decision-making processes.

Furthermore, well-established planning methods like mapping of different geo-spatial and user behaviour data-sets do not convey the dynamic aspect of the built environment in real-time. Therefore, other digital tools like simulation models and tangible user interfaces, attempt to solve this problem and are introduced in the following chapters.

**This work addresses the lack of a holistic approach and incorporation of dynamic patterns in planning processes by investigating how time and direction changes in agents, like trains, tourists or ships, affect spatial transformations. The thesis proposes a decision support tool that uses the results from these investigations to inform decision-making in planning and design tasks.**

A broader field of problem is also addressed. Spatial decision-making usually takes place within a particular field. Whether it would be Arctic tourism, resource extraction or infrastructure, it highlights the problem that Rem Koolhaas applies to architecture and urbanism in his essay ‘Bigness or the problem of large’. He says that “The diverse, multicultural, cybernetic global reality is so powerful that architecture, urban planning and design, become limited to localised physical sites which are no longer adequate as a strategy of shaping built environment” (Koolhaas, 1994). Therefore, finding new ways to connect decision-making activities for a built environment at the local and global levels are in an urgent need.

Looking at the Arctic as a complex system, not separating its narratives but joining it, expands, rather than limits its spatial identity. It is reflected in the joined reports by the Arctic Council, the rise of collaboration projects between Arctic universities, the Arctic Business Forum, individual nation-state Arctic programmes and others.

## 1.3. Objectives

The main objectives of this thesis are:

- to deepen the understanding of time and direction patterns and its role in on-going Arctic spatial transformations.
- to explore a new planning method and tool possibilities that incor-



porate design thinking and support stakeholders early in the decision-making processes, thereby allowing designer to better understand the spatial decisions done long before he/she joins the project.

- to investigate how such tools and methods can empower the designer with more varied skills for facing less and less predictable futures.

#### 1.4. Background

While some still see the Arctic as remote in the sense of both political imaginary, economic development and living standard (Schweitzer et al., 2017), others, like China, render the Arctic as a very close region, full of untapped resources and outstanding opportunities for mobility and technology (Schweitzer et al., 2017).

The region can be seen as a fluid space whose boundaries and form of governance are still blurred. Legally there exist eight Arctic states (Finland being one of it), followed by several “almost” Arctic states, like China, Japan and South Korea. The national governments, multiple international organisations, like the United Nations or Arctic Council and non-state actors like Indigenous People, have mechanisms to manage the legal, physical, cultural and commercial impacts on the transformation driven by actors from different fields.

According to the Arctic Human Development Report (AHDR), increasing global interest is visible in all key sectors – mineral resources, shipping, infrastructure, cultural narratives and Arctic tourism (Nordic Council of Ministers, 2015). They are presented in detail in Chapter 2. The relations among stakeholders from these sectors are complicated. However, they are strongly interdependent, forming systems that operate beyond one discipline’s framework (Nordic Council of Ministers, 2015). These conflicting relations are well manifested in projects like the Arctic Ocean Railway.

##### *Northern Sea Route*

Everyone now observes the Northern Sea Route (NSR), but it is not a new marine construct — the route existed for many decades and only now due to climate trends it gained a strong economic incentive (Schweitzer et al., 2017). Maritime traffic in the Arctic is already considerable, e.g. in 2013, 26 voyages have been made between Europe and Asia (Humpert, 2014). While the traffic is expected to increase in future years, Arctic shipping still has many obstacles to overcome to make this route feasible and less environmentally questionable (Stephen, 2018).

Climate change makes accessibility through the NSR more available, shortening the shipping distances by a third. It could result in faster transportation and fewer fuel use. Currently, the Suez Canal faces marine traffic jams, depth constraints and long shipping times that result in high gas emissions. These factors make the NSR an attractive alternative.

Currently, considerable attention is received from the non-Arctic states, especially the Asian newcomers to the Arctic Council, who recently received an observer status — China, South Korea, Japan, Singapore,

and India (Moe & Stokke, 2019). Such a situation concerns local Indigenous People across the Arctic, environmentalists and to some degree Arctic states, especially when the new route vision is promoted by self-called “near-Arctic” resource and energy-hungry states like China.

Indigenous people are concerned about land fragmentation where new infrastructure is placed to serve the ever-more expanding global transportation network along the NSR (Clare, 2018).

Arctic states worry that allowing the Chinese market to expand unstoppably might create repercussions and neglect local business, development opportunities and the political and legal status quo (Brady, 2017).

Meanwhile, scientists and environmentalists are mainly concerned about the natural environment. The opening of the NSR signalises climate change in the region that might force species and populations to migrate as the local habitat is lost (Emmerson & Lahn, 2012). These concerns are relevant to this thesis, as to various degrees, they represent the region's spatial characteristics.

### *Arctic resources*

One of the most discussed and controversial perspectives on the region is its natural resources (Similä & Jokinen, 2018). Due to increasing accessibility, untouched Arctic resources can be finally explored.

The global community around the world requires raw minerals, but its extraction at the same time has adverse impacts on the local communities and alter the surrounding environment (Similä & Jokinen, 2018). Projects — mines, pipelines, oil platforms — driven by these global needs, often show little sensitivity to existing ecologies, cultural traditions and lifestyles, which it affects, e.g., reindeer herding (Stephen, 2018).

Impacts vary depending on the spatial scale, type of activity, stage of development and technology (Suopajärvi, 2015). Industrial development for resource extraction comes with investments in infrastructure, as a necessary pre-condition for bringing resources to markets outside the Arctic. Therefore, while the region in its mental imaginary is far-away, poorly connected and not disturbed by urbanisation, practically, it is already crossed by several major connectivity corridors that support resource movements.

### *Arctic infrastructure*

Emerging infrastructure projects are mostly driven by outside Arctic forces like the global demand for resources. The complicated relationship between global powers and local communities often results in undermining the latter. This power imbalance is particularly relevant due to created inclusion and exclusion, inequality and marginalisation (Schweitzer et al., 2017). Because of that, infrastructure development — if it must happen — must be sustainable and inclusive (Clare, 2018).

The result mainly depends on the strategies of how the infrastructure would be built. On one hand, a new territory-crossing railroad could

considerably change indigenous Sami landscapes. Herders and hunters have to find new routes due to the fragmentation and pollution of their pastures (Panzacchi et al., 2013). On the other hand, they could integrate the railroad into their food supply and mobility between villages and herding camps, use it for developing the education by expanding horizons, to advance local trade and to up-skill the population. The given example shows the different sides of infrastructure development.

Finally, with low population density and sparse settlements, infrastructure becomes a distinctive spatial element in the wild landscape that, in many cases, conflicts with the image on which increasing Arctic tourism is based.

### *Arctic tourism*

Tourism is a rapidly growing economic sector in the region. While the variety of tourism activities is wide, all of these activities are mostly forms of nature-based tourism (Similä & Jokinen, 2018). With the increasing accessibility, due to changing climate trends and infrastructure development, there are more chances for everyone to experience ‘the last frontier’ of untouched wilderness. In some cases, the tourism activities are also used as a conservation programme to the indigenous people lifestyles (Müller & Huuva, 2009). For example, being distinctive in its identity, Sami lifestyle, herding and unique language, became one of the attractions for tourists in Finland, generating additional income for small businesses and individuals.

The idea itself is contradicting, since increased flows of tourists, stimulates more projects, making the Arctic regions more and more urbanised, while at the same time losing its branded pristine image (Pashkevich, 2014).

## **1.5. Arctic Ocean Railway**

Ports along the NSR work as gateways to and from the mainland. The missing link between the port and final destination is usually a railway, road or a pipeline.

In the recent year, a concept of The Arctic Ocean Railway as a part of the infrastructure development vision for the Nordic region was discussed in public media and reports many times. It should be seen as part of the transport system connecting with the Arctic Ocean in the north and with the controversial Helsinki-Tallinn tunnel and the under-construction Rail Baltica in the south. It would connect southern and northern Europe, as well as Europe and Asia.

In 2018 a joint team of the Finnish Transport Agency and Norwegian Railway Directorate experts was responsible for drawing up the Arctic Ocean Railway Report (Finish Transport Agency, 2018). While the report discusses five different connection options, this thesis work focuses on the Kirkenes-Rovaniemi route, since it is the route with most opportunities and challenges.

The biggest confrontation against the project is received from the

Finnish Sami community and the Sami Parliament because the route would create severe implications for herding patterns and cause landscape fragmentation (Sanila-Aikio, 2018).

Meanwhile, improved food security, new tourism and mobility patterns in the whole country and more robust social structure are the arguments supporting the project's vision. Currently, the majority of Finland's imports and exports are transported via the Baltic Sea, making it vulnerable in a crisis. The new railway would strengthen Finland's logistical position (Finnish Transport Agency, 2018). The route would run through main population centres and resorts, multiple mining locations and nature reserves. This could create different tourism, urbanisation and mobility patterns in the whole country while employing a high number of people in the Lapland region.

If designed carefully, the railway has potential to become an example of a socially robust infrastructure that serves as a 'region-forming' enterprise, dominating many fields of the social, economic and political life of local communities, combining the elements of technological and social engineering (Finnish Transport Agency, 2018).

Until now, all forecasts show that this alternative is not profitable. However, this may change if one big project would appear along the railway, e.g. expanding existing mining operations would make an impact on the railway's feasibility. A more detailed description of the Arctic Ocean Railway is presented in Chapter 3.

## **1.6. Systems Thinking**

Due to the complex and dynamic nature of the Arctic region, Systems Thinking is chosen as a theoretical framework (Richmond, 1994; Senge, 2006; Sweeney & Sterman, 2000).

Systems Thinking, is a holistic approach to analyse a system. It focuses on the way that the system's constituent parts interrelate and how systems work over time within the context of larger systems (Meadows, 2008). It provides a standard method for the study of societal and organisational patterns and offers a domain-independent vocabulary. Systems Thinking derives from a broader field known as General System Theory (von Bertalanffy, 1968).

According to Donella H. Meadows, a system is "[...] a set of elements or parts that is coherently organised and interconnected in a pattern or structure that produces a specific set of behaviours" (2008). Patterns can be seen as one way to approach a system. They can be defined as "[...] relational frameworks that simultaneously describe a project: they reveal structures, processes, and relationships and it structures the physical frameworks that give shape and form to the built environment. They do not exist as entities themselves but only in relations between or among things" (M'Closkey & VanDerSys, 2017).

When looking at the Arctic through the Systems Thinking lens, the subsystems of it, like infrastructure, herding or shipping, have some dynamic variables in common and form patterns: time and direction, i.e.

schedule and lifecycle, or northbound-southbound and inward-outward headings.

The relevance of Systems Thinking and dynamic patterns in the Arctic context, its correlation with the chosen problem and applications to address it are discussed in Chapter 4 and 5.

Time and direction are not so easily integrated into planning and design processes because traditional tools and methods are not typically dynamic and do not include these aspects in the spatial analysis. Therefore, these two system-defining variables became a starting point of designing a decision support tool for planning and design tasks.

### **1.7. Urban Simulation tools**

Current urban planning and architecture strategies aim to merge temporal and spatial data to enhance the well-being of urban populations (Crooks et al., 2008). To understand it better, stakeholders need tools that address the internal correlations between multiple dimensions of the regions, cities or specific places. Digital simulation conveys the dynamic aspect of the built environment in real-time. By merely presenting the interaction of critical variables, they allow stakeholders to explore changing processes.

A range of urban simulation tools and platforms for various purposes is available to this date (see Chapter 6). The general purpose of such simulation tools is to help users understand the impact of decisions in a quantitative fashion. Therefore, there exists an increased focus on easy-to-implement simulation modelling platforms that are able not only to create simple but also spatially explicit, complex models with different levels of representation. The CityScope setup, developed by MIT Media Lab researchers could be named as an example of such simulation platforms used in different projects (Alonso et al., 2018; Grignard et al., 2018; Noyman et al., 2017).

A simulation model is usually evaluated by the extent of the insight it gives, discussion it stimulates, innovation it inspires, and the extent it helps to resolve societal problems (Arctic Council, 2016). Using a model as a decision support tool in planning and design tasks represents an opportunity to combine quantitative and qualitative theories, change between observations and hypotheses within the same framework (Crooks et al., 2018).

The tool used to simulate agent behaviour in this thesis is GAMA — an open-source modelling and simulation platform. It aims at providing modellers with tools to develop and experiment highly complex models through a well-thought integration of agent-based programming, and GIS data (Taillandier et al., 2019).

The type of model discussed in this thesis (see Chapter 7) and used for the application is based on the pattern-oriented agent-based approach (POM-ABM). The agent-based approach (ABM) is a style of thinking that defines the system through individual, autonomous entities at many different levels of spatial aggregation (Crooks et al., 2018). Pattern-oriented modelling (POM) is an approach to bottom-up complex systems analysis

with emphasis on patterns, where agent's behaviour is translated into reoccurring events-forming patterns (Grimm et al., 2005).

In this thesis work, the CityScope tangible user interface (TUI) is used to facilitate the simulation model (see Chapter 9). It is an ongoing research theme at the MIT Media Lab CityScience group. Projects, where it is used, are mainly demos — experiments and research done at MIT Media Lab, usually in the form of generic and scalable tools or demos for local planning processes (Hadhrawi & Larson 2016). The CityScope aims to visualise the complex urban data, simulate the impact of real-time interventions and support stakeholders' decisions by providing a dynamic, iterative and evidence-based process (Alonso et al., 2018).

### **1.8. Methodology and scope**

An agent-based model to simulate and present on-going spatial behaviours in the region is used as the primary design method. Using Systems Thinking allows to abstract the existing world into patterns and presents it only through selected datasets and variables that support the introduced patterns. For example, the agent interdependencies are investigated only in two aspects: time in the form of schedule, i.e. the spatial distribution of agents change over some time, and direction — a characteristic that space or agent has at a given time.

The carried out generic experiments (see Chapter 8) with this model provide the following outputs: collision and direction field maps. These outputs help to evaluate different scenarios and to recognise the most critical moments and locations better when analysing the chosen case study.

### **1.9. Audience**

The primary audience this work addresses is the thesis examination committee, comprising members from speciality areas within the discipline, namely, architectural design, urban planning and urban design. Also, students and teachers investigating how new methods can enrich and diversify the design process and decision-making in planning and urban design tasks. It is particularly relevant in the contexts where existing approaches are not adequate to understand complex systems and on-going spatial transformations in the built environment.

The broader aim is to reach a wider audience of stakeholders that could participate in shaping the Arctic environment through iterative, evidence-based means. Such stakeholders could be Indigenous People communities willing to better understand how their local habitat is interdependent on other acting forces, like resource extraction and infrastructure entrepreneurs, public development agencies and municipality planners.

### **1.10. Impact**

For the discipline and practice of architecture and urban planning and design, the thesis offers a way to reconsider the design process by addressing

the potential of dynamic patterns in decision-making. Dynamic patterns support other planning methods by being particularly suitable for complex systems.

Additionally, facilitation of computational planning methods, together with the use of Systems Thinking, opens doors for additional insights into the urban planning challenges. Exercising different speculative scenarios through tools like simulation models can help planners to easier trace decisions and actions that create boundaries for design tasks and to get more prepared for possible futures.

The proposed design provides a way to visualize the information that can otherwise not be clearly expressed and allows users to exercise judgment for different decisions in the project efficiently.

### **1.11. Limitations**

The proposed planning and design decision support tool has some limitations. However, many of them are model-specific and could be solved with further development.

First, the final output does not show precise results due to the chosen scale but instead gives speculation of a general situation. As a result, a certain level of data reduction is inevitable when working with large-scale planning projects.

Second, the development of this simulation model requires a vast amount of data, which is not always available at hand. Furthermore, there exist strong dependencies of the input data and the final results, where the input reliability depends on experts' involvement.

Finally, the computation power is a well-known limitation among similar projects.

### **1.12. Criteria**

The main criteria for this thesis success are:

- The application's fruitfulness for decision support in planning and urban design tasks. The model's utility can be best measured by the extent to which the model gives insight, stimulates discussion, inspires exploration and innovation and helps to resolve spatial challenges.
- The improvement of the user's comprehension of time and direction patterns' role in planning and design tasks and easy use of these two patterns in spatial analysis.
- The smooth and easy interactiveness with the CityScope Lapland table.

### **1.13. Thesis structure**

The design of the decision support tool and methodology for urban planning and design tasks is structured in four steps: 1) selecting and discussing spatial narratives 2) distinguishing unique patterns 3) implementing patterns in the simulation model and generating outputs 4) facilitating the



model with the CityScope table (see Figure 1). Each step addresses different user or stakeholder groups. A short video visualizing these steps is available in the following link:

<https://vimeo.com/388881825>

These four steps in this thesis spread across a research and an application parts. PART I draws on the project's theoretical framework, using the existing background research on the topic and covers the relevant theories.

Chapter 2 describes the complex nature of the Arctic region through its spatial narratives, and Chapter 3 introduces the Arctic Ocean Railway project as the case study. Systems Thinking and dynamic patterns are introduced in Chapter 4. Further, in Chapter 5, the author distinguishes the relevant Arctic patterns in herding, tourism, resources, shipping and infrastructure. This prepares the reader to be able to relate to the parametrized patterns' versions implemented in the simulation model.

PART II shows the creative part and design explorations of this master thesis. It introduces the application method of research results in a decision support tool for urban planning and design tasks.

Chapter 6 presents the simulation tools and agent-based modelling strategies. Chapter 7 describes the simulation model structure design and workflow. Chapter 8 discusses the possible potential uses of these outputs through a series of generic experiments. The main outputs — dynamic collision maps and direction field maps with additional displays — are then embedded and facilitated in a tangible user interface, presented in Chapter 9.

Chapter 10 presents the main findings and reflections on the introduced design methodology. Furthermore, recommendations and outlooks are included to briefly present the possible directions for further development.



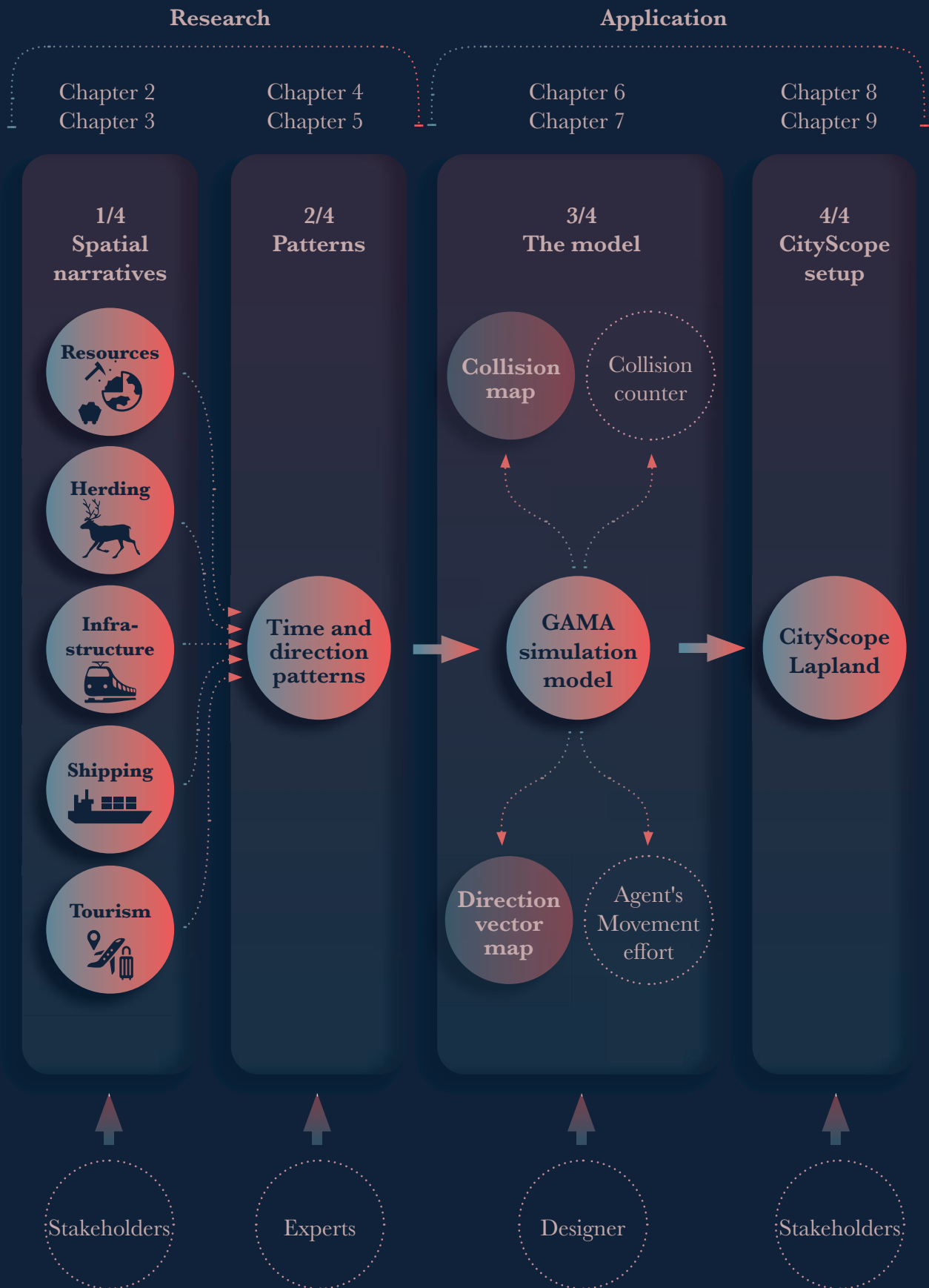


Figure 1. Diagram showing the main design steps of the proposed decision support tool for urban planning and design tasks.

# Chapter 2

## *Intro*

*This chapter presents the most important characteristics and on-going spatial transformations that are common across the Arctic countries.*

*The chapter discusses the changing role of global and local agents in the region's spatial governance processes. Its goal is to inform the reader about re-emergence of the Northern Sea Route relevance and its perspectives, the more than ever-increasing importance of connectivity, the intensifying race for Arctic resources and the boom of nature-based tourism, all reshaping the livelihoods of local populations.*

## **2. The global as a new local**

### **2.1. The time of change**

Global warming holds power to redefine the economic, political, and human structures of the North. On the one hand, the emissions created globally affects the Arctic on multiple levels twice the speed than elsewhere in the world. On the other hand, the effects of the warming Arctic create consequences outside of the region (Clare, 2018). Furthermore, it is now commonly accepted that the factors playing a crucial role in the region's transformation are often not local, but located far away from the Arctic.

As the ice melts and permafrost thaws, a new Arctic is emerging — and like all new realities, it generates many speculations about the future uncertainties. Maps from recent years show that if once recorded regular sea ice extent and expanses of permafrost now display anticipated ice retreats and large-scale thaws. The Arctic Ocean could be mostly free of sea ice in summer as early as 2030 (Emmerson & Lahn, 2012). Therefore, it is very likely that the Arctic in the future will look very different from how it looks now. For example, different precipitation, snow cover, and wildfire patterns might affect grazing opportunities for reindeer and other herded animals, which result in altered habitat uses and migration patterns (Stephen, 2018).

One of the essential characteristics of the Arctic region is the interconnectivity between natural phenomena and human's activity presence. Therefore, discussing climate change in this region requires to include its effects not only on the natural and built environment but also how those changes cascade in the daily lives of local populations, businesses and resource industries. The changing patterns of migration, fishing or connectivity have impacts on cultures, traditions, identities and relationship to space.

Much attention in Arctic development is given to the increasing potential of connectivity due to the opening Arctic Ocean. However, such changes can also induce a decrease in access and movement (Stephen, 2018). The destabilizing roads and railways due to decreasing permafrost, or coastal erosion due to waves could be mentioned as few examples (Kostopoulos et al., 2019).

### **2.2. The Arctic agents**

The most recent wave of interest in the North sees the Arctic as an economic and political region in a globalised world. This perspective is strongly connected to the climate change discourse in which the Arctic is becoming central in a new colonialist resource grab (Hemmersam, 2016). What can be observed currently in the Arctic has shocking similarities in spatial and social distances between most powerful builders and built objects to colonial legacies (Schweitzer et al., 2017). Because of that, local communities face challenges to preserve its unique existence due to urbanisation

processes, e.g. new industrial cities are emerging and increasing the use of local resources by agents from far away.

Based on that, one can distinguish at least two agent types in the Arctic. The environmentalists and local Indigenous People communities wish to preserve the positive parts of life in the Arctic - like the pristine natural environment. Meanwhile, the global community, business and industry entrepreneurs show an increasing demand for new prospects for natural resources that still lays in the region.

The integration of the Arctic region into the global economy – principally through energy and transport – likely will further increase its geopolitical relevance in the region and disbalance the power relation representing these two sides. The Arctic can accommodate diverse pursuits, but only to the extent that they are either compatible or else separated by enough time and distance. Some activities may conflict at first, but be reconciled if both sides agree on shared goals and mutually acceptable conditions (Arctic Council, 2016).

A place that once was considered as non-human and remote now is emerging as all connecting fluid space. If in the past, harsh Arctic climate defined the rules of life for the existing sparse population in the North, now the changing Arctic affects the global population worldwide, and global actors affect the climate in the Arctic resulting in changing environment for the Northern populations. This combination of warming physical conditions and increasing attention is not only changing the Arctic, but it is also changing how humanity sees the Arctic (Clare, 2018). For example, based on statements in public rhetorics (State Council Information Office of the People's Republic of China, 2018), China encourages the creation of global polar culture to justify its involvement in the Arctic infrastructure and resource extraction projects.

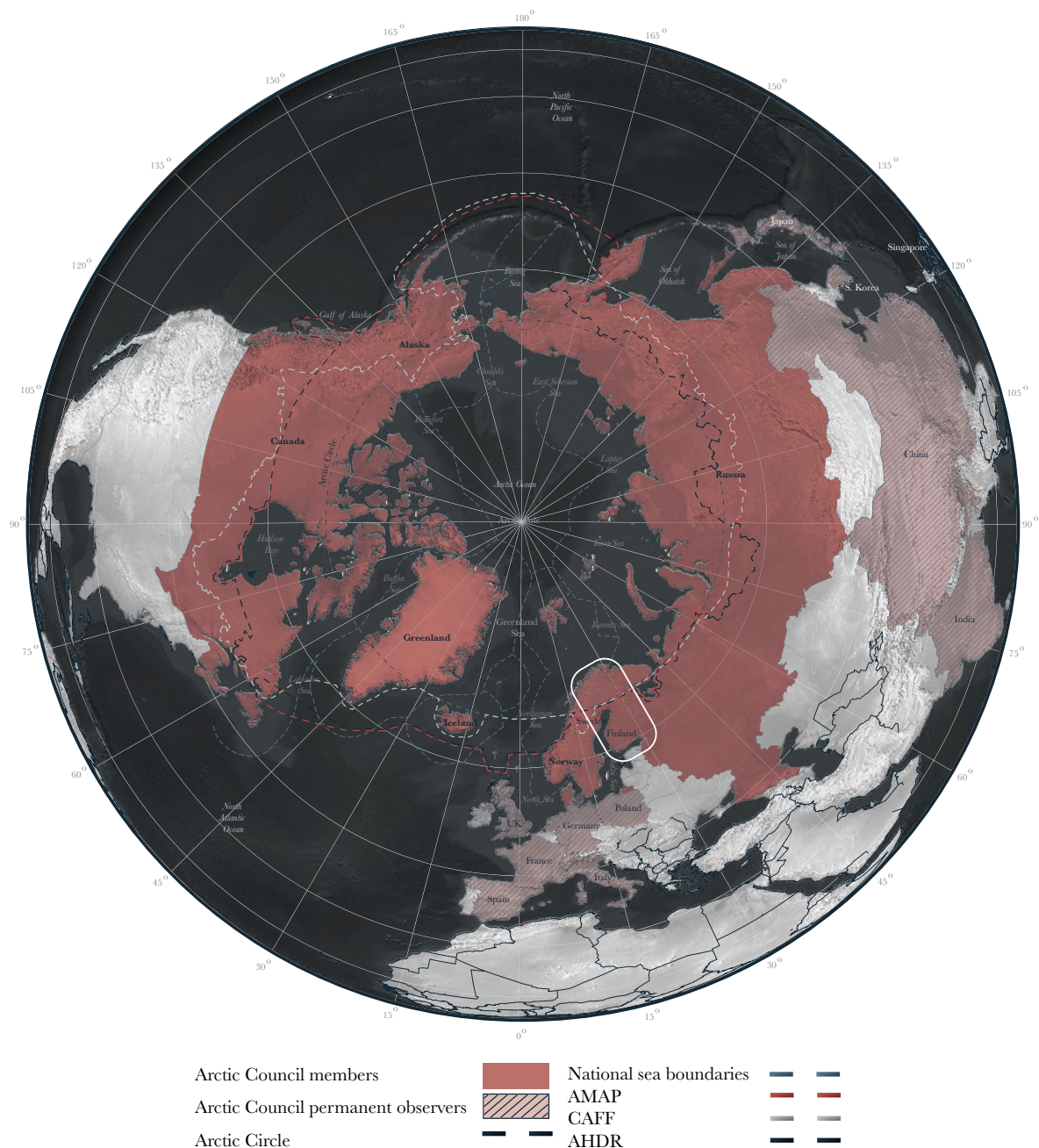
**Therefore, it is crucial to find a balance of decision-making power among local and global agents.**

Currently, the official Arctic legal boundaries and spatial divisions are defined by various authorities, ranging from non-governmental, non-profit organisations to national governments and profit organisations. The Arctic Council<sup>1</sup> serves as a leading intergovernmental forum. It promotes necessary cooperation, provides coordination and helps Arctic States, indigenous communities and other agents to interact on common Arctic issues, in particular on issues of sustainable development and environmental protection of the region (Arctic Council, 2016). It consists of Arctic-states and Observers (see Figure 2). In addition, six organisations representing Arctic Indigenous People have status as Permanent Participants.

At the moment, there exist two general opinions about newcomers to the Arctic Council. While much of the debates tend to see it as a threat,

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<sup>1</sup> The Arctic Council is a high-level intergovernmental non-profit organisation seeking to ensure and accommodate the necessary debates about the Arctic region (<https://arctic-council.org/index.php/en/about-us>)



Arctic Council:		
<b>Arctic states:</b> <ul style="list-style-type: none"> <li>Canada</li> <li>Kingdom of Denmark</li> <li>Finland</li> <li>Iceland</li> <li>Norway</li> <li>Russian Federation</li> <li>Sweden</li> <li>United States of America</li> </ul>	<b>Permanent Participants:</b> <ul style="list-style-type: none"> <li>Aleut International Association (AIA)</li> <li>Arctic Athabaskan Council (AAC)</li> <li>Gwich'in Council International (GCI)</li> <li>Inuit Circumpolar Council (ICC)</li> <li>Russian Association of Indigenous Peoples of the North (RAIPON)</li> <li>Saami Council (SC)</li> </ul>	<b>Observers:</b> <ul style="list-style-type: none"> <li>Germany (1998*)</li> <li>The Netherlands (1998*)</li> <li>Poland (1998*)</li> <li>United Kingdom (1998*)</li> <li>France (2000)</li> <li>Spain (2006)</li> <li>People's Republic of China (2013)</li> <li>Republic of India (2013)</li> <li>Republic of Korea (2013)</li> <li>Italian Republic (2013)</li> <li>Japan (2013*)</li> <li>Republic of Singapore (2013)</li> <li>Switzerland (2017)</li> </ul>

*Figure 2. Map showing the Arctic region's legal boundaries based on different organisations, the Arctic Council's members and observers.*

some also highlight the opportunities for cooperation that arise through the participation of economically and politically essential players like China (Humpert, 2014).

### 2.3. Arctic Population

*"The Arctic is home to a variety of populations in a constant flux [...]"*  
— Hemmersam, (2016)

In the collective imagination, the Arctic region seems like a remote land with the extensive natural landscape and very sparse population. However, the reality might be different. Indigenous People have inhabited the Arctic for thousands of years, tourists are flooding the north and new industrial cities attracting population are popping up.

Discussing the Arctic population is an ambiguous task. While various Indigenous People groups stand as a well known physically-based population group in the Arctic, one could also include the short-term influx of population through tourism or industrial activities. The two Arctic population groups discussed in this thesis are Indigenous People and tourists.

The Arctic areas are inhabited approximately by four million people (Nordic Council of Ministers, 2015). It is estimated that over 40 different ethnic groups are living in the region (Nordic Council of Ministers, 2015). Arctic Indigenous People include Sami in circumpolar areas of Finland, Sweden, Norway and Northwest Russia, among other ethnic groups (Stephen, 2018). While not all population is Indigenous People, this minority group plays a vital role in the region's governance through various legal bodies, e.g. Sami Parliament of Finland<sup>1</sup>.

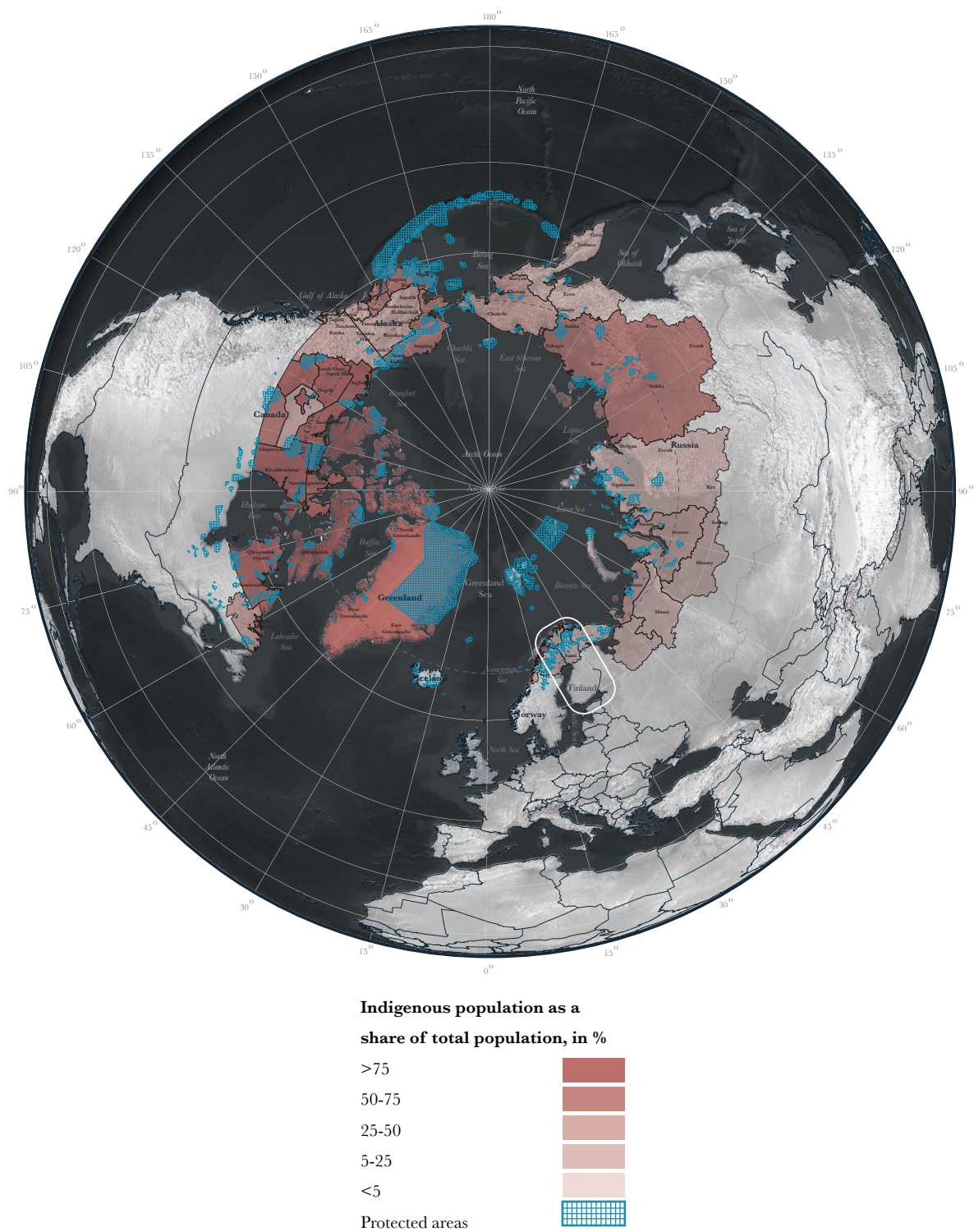
There exist a significant variation of cultural, historical and economic backgrounds among these groups. However, most of them have already undergone substantial changes. The changing patterns in resource extraction, climate and mobility affect their traditional activities, force migration from rural areas to urban centres in the Arctic. Often these changes negatively affect Indigenous People, threatening their existence altogether. Therefore, various actions are taken to prevent and mitigate these changes. For example, the unique role of Indigenous People in the Arctic governance is reflected in their special standing as traditional knowledge- and rights-holders in Arctic affairs, e.g. Arctic Council (Stephen, 2018). Also, a range of protected areas spans Arctic territories, often where Indigenous People are permanently located due to suitable natural settings and long traditions (see Figure 3).

Climate change might directly or indirectly affect Indigenous People. For instance, harvesting and hunting are challenged by changing weather conditions like temperature and precipitation and herding is affected by increasing land fragmentation. Infrastructure projects like roads or railways create corridors for invasive species to come to the region. As

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<sup>1</sup> The Sami Parliament is a self-governed political body that represents public opinion on national and international levels of Sami indigenous people in Finland. <https://www.samediggi.fi/?lang=en>





*Figure 3. Map showing the distribution of the Indigenous People's population and protected areas in the Arctic region.*

a result, this may affect the entire ecosystems and tightly to it connected populations (Stephen, 2018).

The influx of newcomers into the Arctic region has substantial impacts for livelihoods and lifestyles, e.g. it creates pressure on existing physical and social infrastructures. However, this influx also might provide opportunities in terms of mobility, advanced education, career promotion and empowerment through local knowledge (Stepien et al., 2016).

The Arctic regions more than ever emerge as new destinations for tourists. This is due to easier accessibility, increasing awareness and demand for so-called "last chance" tourism to see the wild north before the ice melts. In some Arctic areas, tourism is one of the fastest-growing economic sectors (Stephen, 2018). For example, on the European side, distinctive tourism trends can be seen in cruise shipping in Norway and winter holiday tourism in Finnish Lapland. Since tourism gives a strong economic stimulus to the vulnerable communities, it is often used as a conservation strategy (Müller & Huuva, 2009). On the other hand, increased tourist numbers and nature exploitation for providing the desired service often degrade environment (Pashkevich, 2014).

These two co-existing population sources sometimes might support each other. On the one hand, Arctic tourism is often nature-based and nature is the foundation of Arctic traditional ways of life. Therefore, thriving Arctic indigenous communities might attract more tourism. On the other hand, this might also cause disruptions in the indigenous communities, since the more profitable tourism sector might neglect the local activities (Müller, 2015).

## 2.4. Northern Sea Route & Arctic shipping perspectives

*"To follow the Silk Road is to follow a ghost. [...] It is not a single way, but many: a web of choices."*  
— Colin Thubron (2007)

Everyone now observes the Northern Sea Route (NSR). Currently, considerable attention is received from the non-Arctic states, especially the Asian newcomers to the Arctic Council, who recently received an observer status - China, South Korea, Japan, Singapore, and India (Moe & Stokke, 2019). China even names NSR the Polar Silk Road<sup>1</sup> - the product of globalization to facilitate global trade and economic integration (Lim, 2018).

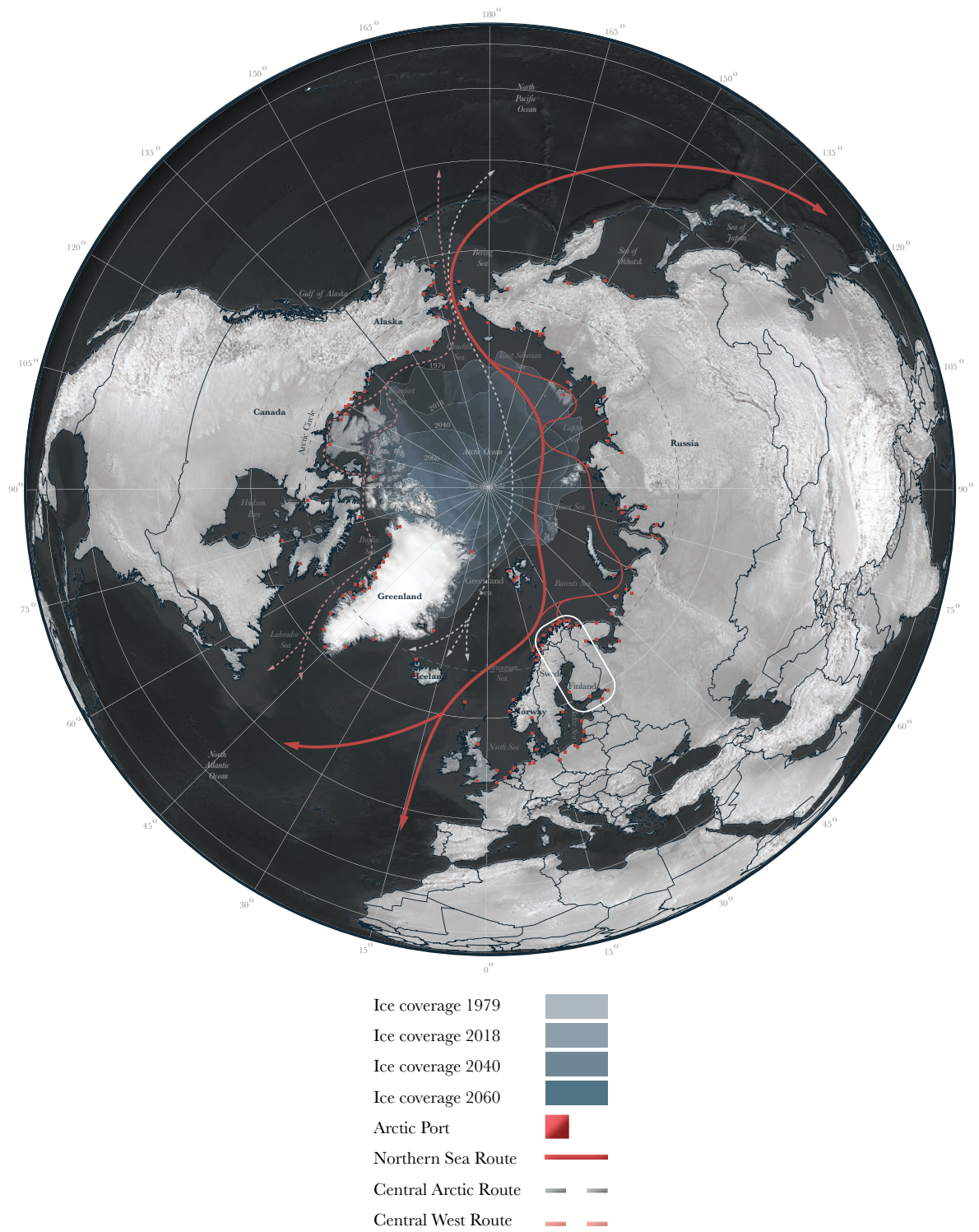
However, it is not a new marine construct as the route existed for many decades, but only now, due to climate trends, it again gained a strong economic incentive (Schweitzer et al., 2017). A thirty-year ice retreat could cut shipping distances between Northwest Europe and the Far East by a third. It could result in faster transportation and fewer fuels.

Furthermore, the opening route creates impacts far beyond the

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<sup>1</sup> China envisions the Arctic Ocean route to be part of its grand strategy (the Belt and Road Initiative (BRI) by calling it the Polar Silk Road in its White Paper released in 2018 ([http://english.www.gov.cn/archive/white\\_paper/2018/01/26/content\\_281476026660336.htm](http://english.www.gov.cn/archive/white_paper/2018/01/26/content_281476026660336.htm)).





*Figure 4. Map showing the Northern Sea route, the main Arctic ports and the current and historical ice accumulation boundaries.*

Arctic Ocean. In order to serve the ever-more expanding global transportation and trade network along NSR, new railways, roads, ports and pipelines have to be taken into account when discussing the impact of NSR. Such a situation concerns local Indigenous People across the Arctic, environmentalists and to some degree Arctic-states.

In the global supply chain, over 90% of the world's traded goods are transported by sea. This also carries significant adverse environmental impacts. Travelling times are long, meaning, shipping produces high amounts of gas emissions. Furthermore, the Suez Canal faces multiple challenges: marine traffic jams and depth constraints. Because of these challenges, the NSR is emerging as an alternative, with shorter travel distance and time (UNCTAD, 2018). This attention is emerging also due to growing international trade driven by the rise of Asian economies, which require increasing imports of energy and raw materials (Brady, 2017).

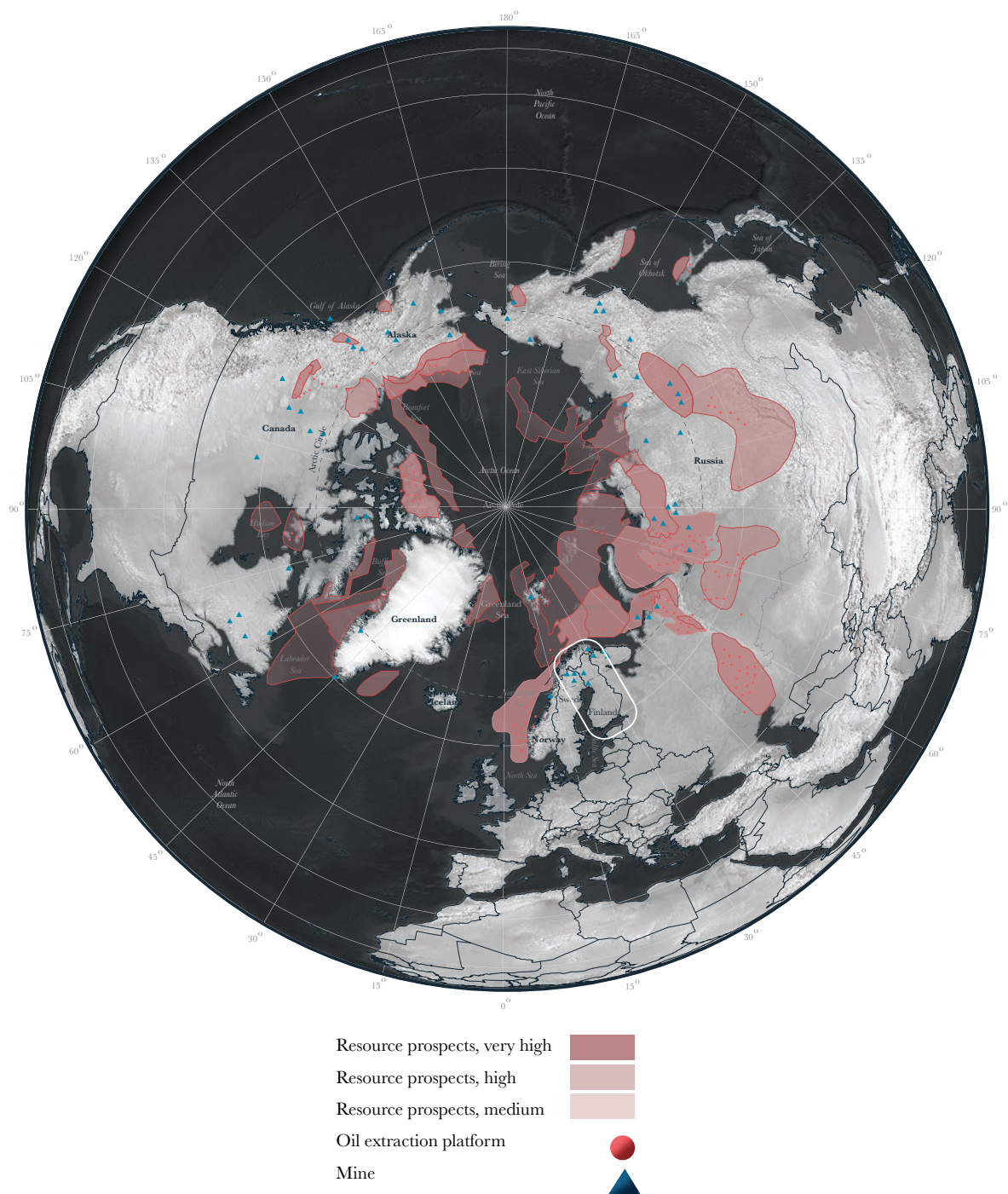
The marine traffic is expected to increase in future years, but Arctic shipping still has many obstacles to overcome to make this route feasible and less environmentally questionable (Stephen, 2018). For example, the Finnish Transport Agency see low water depths and demanding ice and weather conditions as the main challenges. Also, the entire length of the NSR is only ice-free during September and October (2018).

Furthermore, a substantial lack of diversification can be observed in NSR, especially in terms of country of origin. Since NSR follows Russian coasts (see Figure 4), it is primarily a domestic supply and export route for Russia (Humpert, 2014). Around 10.2 million tons of goods were transported through the NSR in 2017 (Staalesen, 2018), the majority of which were internal shipments within Russia or Russian exports. The key hubs for this regional shuttle service are the cities of Murmansk and Arkhangelsk in the west, Ob Bay in the centre, and Pevek in the east. Therefore, having European ports would increase corridor's diversity in operating firms and agents (Stephenson et al., 2014). For example, Finland, as one of the global leaders in icebreaker design, polar shipbuilding, ice technology and fleet operation could gain many economic profits (Lapland Chamber of Commerce, 2018). Examples like these prove that new branches for Arctic economies can be created or further developed due to the intensification of traffic in the region.

## 2.5. Arctic Resources

*For the past four centuries, access to the Arctic has meant access to natural resources.*  
— Gritsenko (2018)

There are several factors significantly affecting the resource extraction industry interest and the pace of exploration and production in the region. Among the most influential are geography, geology, environmental regulations, political climate, availability of infrastructure, and history of resource development in different parts of the Arctic (Shapovalova & Stephen, 2019). For example, due to challenges of working in extreme conditions, offshore exploration and extraction tend to develop at a slower pace



*Figure 5. Map showing the Arctic region resource potential, the main currently active extraction sites and their types.*



and with more uncertainty than in the mainland. Exploitation also differs across resource provinces. For instance, the Barents Sea region seems to be less risky and difficult location than other Arctic offshore areas (Emmerson & Lahn, 2012). However, mining projects often offer the better long-term potential for economic development than oil and gas, with a larger permanent and local workforce and a project lifetime of several decades, from prospecting and production to closure and rehabilitation (Emmerson & Lahn, 2012).

Resource extraction projects cluster across all Arctic states (see Figure 5). Numerous large-scale resource extraction projects manifest strong spatial transformations. Few of them are the Ukhta-Torzhok-2 pipeline<sup>1</sup> in Russia, the Goliat Field<sup>2</sup> in the Norwegian shell bed, Kiruna iron mine<sup>3</sup> in Sweden. Furthermore, Rosneft<sup>4</sup> signed an agreement with China National Petroleum Corporation (CNPC) in 2013 to explore fields in the Barents and the Pechora Sea (Staalesen, 2013) and CNPC acquired a 20% share in Yamal liquified natural gas (LNG) project<sup>5</sup> (Humpert, 2019).

Such projects, driven by global, outside the Arctic demands strongly conflict with local communities and show little sensitivity to existing ecologies, cultural traditions, lifestyles. The impact of these projects on the environment, economy and society vary depending on the spatial scale, type of activity, stage of development, the technology and infrastructure (Jantunen & Kauppila, 2015).

On the other hand, constructing new infrastructural facilities or resource extraction sites employs many people. There are cases, usually, from local regions where the population and employment increases, new companies get established in the area, housing construction expands, investments are made in upgrading schools, infrastructure and cultural facilities. All these changes are indicators of urban growth (Nordic Council of Ministers, 2015).

## 2.6. Arctic Infrastructure

*“Infrastructures are matter that enable the movement of other matter.”*

— Larkin, (2013)

For a long time, the Arctic could have been defined as cold, uninhabited, the last frontier for humanity. Therefore, emerging infrastructure projects

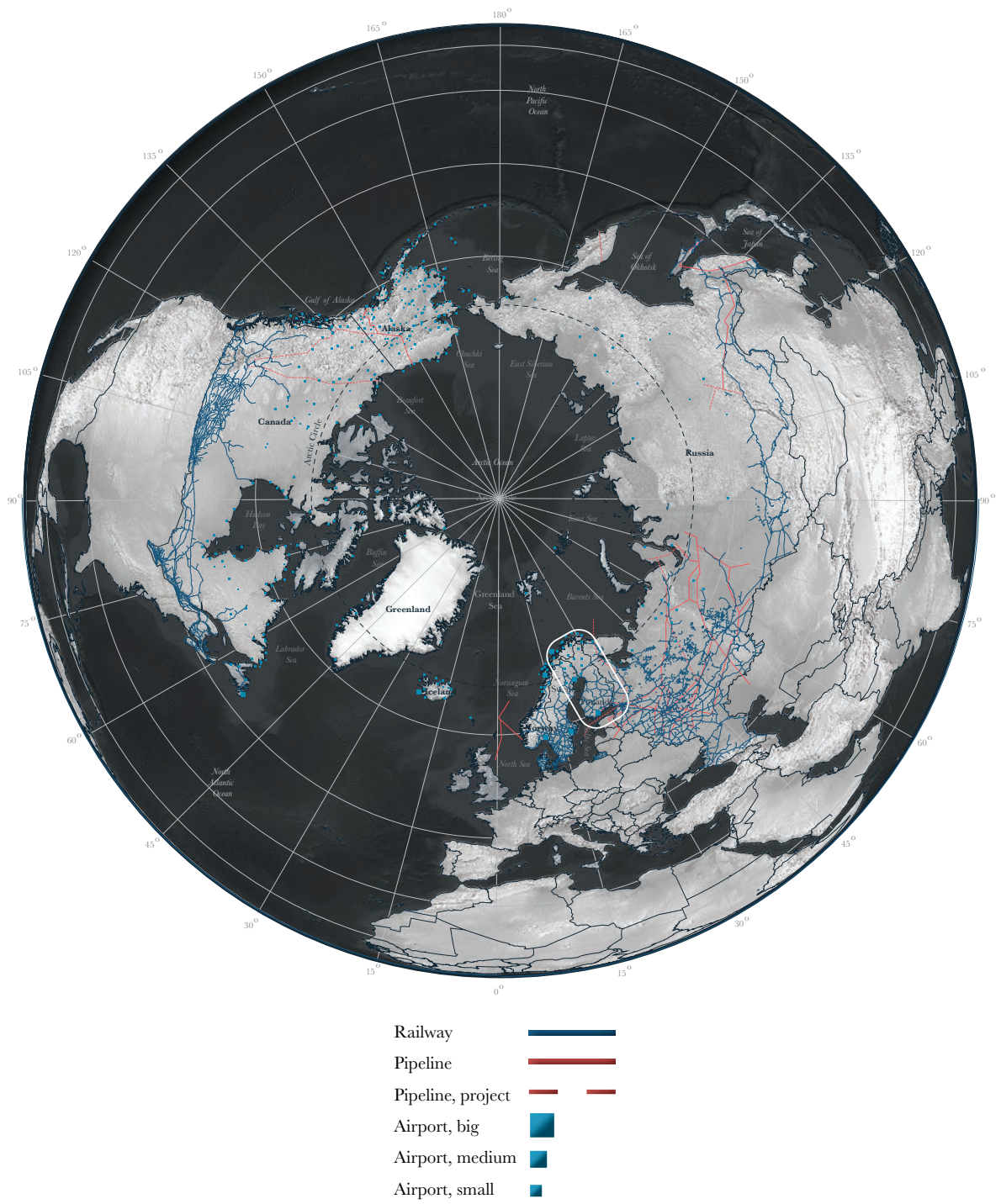
1 The key pipeline development, expanding the northern corridor of Russias Unified Gas Supply system and operated by Gazprom (<https://www.gazprom.com/projects/ukhta-torzhok/>).

2 Offshore oil field in the Norwegian waters, 85 km away from Hammerfest (<https://www.norskepetroleum.no/en/facts/field/goliat/>).

3 The Kiruna mine is the largest modern underground iron ore mine in the world that has dramatic spatial implications for the settlement near it (<https://www.mining-technology.com/features/moving-a-town-to-save-a-mine-the-story-of-kiruna/>).

4 Rosneft is the leader of the Russian oil sector controlling many large-scale projects in Russia and abroad ([https://www.rosneft.com/about/Rosneft\\_today/](https://www.rosneft.com/about/Rosneft_today/)).

5 Yamal LNG is one of the largest and most complex liquified natural gas projects in the world (<http://yamallng.ru/en/>).



*Figure 6. Map showing the Arctic region infrastructure network and its types.*

in the Arctic region have a significant role. With low population density, sparse settlements, infrastructure becomes a distinctive spatial element.

Infrastructure developments in the Arctic usually come late or at a slow pace. The infrastructure can be external or internal, depending who it is using it. Thus, the current vision of the NSR with more transit, national and transnational railway connections, mines, pipelines, not without reason concerns local Indigenous People, environmentalists and to some degree Arctic states. Especially when this NSR vision is promoted by self-called “near-Arctic” resource and energy-hungry states like China. (Stephen, 2018). Therefore, the notion of “infrastructural violence” is particularly relevant due to its mechanisms of inclusion and exclusion, relations of inequality and marginalisation, which can be seen in the relationships between global agents and indigenous groups in the circumpolar North (Schweitzer et al., 2017).

The significant development of infrastructure in the Arctic is on-going and likely will continue to link vast territories in the coming decades (see Figure 6). For instance, the establishment of longitudinal and latitudinal corridors, leading to the key hubs is foreseen in, for example, Russian Arctic infrastructure development. Several existing (Transsiberian, Baikal-Amur) and projected (Transpolar, Transpacific) railroads should play critical roles in the growing Russian Arctic network (Schweitzer et al., 2017).

Because of that, infrastructure development — if it must happen — must be sustainable and inclusive. Implementation of infrastructure necessary for the rest of the world’s demand should not disrupt the natural environment and local people. The result depends on the strategies of how the infrastructure would be built. For example, a new territory crossing railroad could considerably change indigenous Sami landscapes. On the one hand, herders and hunters have to find new routes due to the destruction and pollution of their grounds and pastures. On the other hand, they could integrate the railroad into their food supply and mobility between villages and herding camps, use it for developing the education by expanding horizons, to advance local trade and to up-skill the population.

While many decisions lie with local and national authorities, the cross-border nature of some infrastructure suggests that this is an area for the Arctic Council to play a stronger role. For instance, to ensure that these infrastructure projects benefit people in the region and does not create adverse implications on local livelihoods (Arctic Council, 2016).

Finally, climate change has a negative long-term effect on infrastructure. Permafrost thaw, extreme weather events, flooding, diminishing sea and land ice, and coastal erosion result in unreliable ice roads, damage to houses, pipelines, railroads, airports, seaports, and effects on energy and water supply, which could result in the abandonment of lifestyles and cultural traditions (Stephen, 2018). Thinking of ways how new infrastructure could strengthen the livelihoods of locals, is an essential part of new development projects' implementation strategies. Since good infrastructure is vital for remote communities, new development projects can create better opportunities for interconnectivity and economic activities like tourism and food security (Arctic Council, 2016).

## Chapter 2

### *Reflections*

*The Arctic cultures and identities undergo substantial changes due to the impact of shifting trends in resource extraction, mobility, tourism, shipping, harvesting and hunting.*

*The on-going integration of the Arctic region into the global world is unbalancing the power relation between global and local agents. Tools allowing to perceive the Arctic complexity and better understand the consequences of specific scenarios and interrelationships are essential in order to prevent such an unbalance. The emerging situation in the Arctic already has shocking similarities to colonial legacies. An alternative approach for decision-making and spatial governance could be proposed in order to prevent repeating history.*

*The presented Arctic characteristics are noticeable among all the region's countries. Therefore, similar strategies can be applied to all of them.*

# Chapter 3

## *Intro*

*This chapter introduces the Arctic Ocean Railway concept in detail, as a case study for a new infrastructural project that would be built in a sensitive environment with multiple acting stakeholders. In the upcoming chapters, this case study will help to visualise how the alternative design process for decision-making can be used in similar situations.*

*The chapter covers the economic feasibility, technical challenges and environmental impacts of the railway project, global and local relations, as well as the conflicts it could potentially cause.*



### 3. Arctic Ocean Railway - a solution or a bust?

#### 3.1. The Arctic Ocean Railway in the global transport system

Ports along the NSR work as gateways to and from the mainland. If the NSR came to life, that would create strong directionality in the whole Arctic region. The link between the ports, the resource sites and trade markets is usually a railway, road or a pipeline. Examples of such connections can be found along the Russian coast. Archangelsk, Murmansk, Salekhard, and now, Sabetta ports are connected via road or railway network to further south located territories.

In the recent years, the concept of The Arctic Ocean Railway as a part of the infrastructure development vision for the Nordic region was discussed in media and among various authorities, like the Finnish Transportation and Communication Ministry and the Sami Parliament. A joint team of the Finnish and Norwegian transportation advisory agencies made a feasibility study in early 2018 (Finnish Transport Agency, 2018; Norconsult, 2018). The Finnish Transport Agency also commissioned two separate studies — Sitowise Oy drew up a technical report, while Ramboll Finland Oy analysed the transport potential and impacts of the alternative routes.

The Arctic Corridor<sup>1</sup> within the Finnish territory is not a new concept. Thoughts of connecting the south of Lapland with the Arctic Ocean with a railway link existed since the 1920s (see Figure 7). Officially, the construction of a railway from Finland to the Arctic began in 1893. It has not gone beyond the initial plans after 125 years (Lilja, 2013).

Combined with the concept of FinEst Link<sup>2</sup> (the underwater railway tunnel between Helsinki and Tallinn) and the Rail Baltica<sup>3</sup> being under-construction, the Arctic Ocean Railway would provide an alternative route to connect Europe from north and south (see Figure 8). From the global perspective, the Arctic Corridor would be particularly valuable to Finland and the Eastern European countries linking the Arctic Ocean coasts, the Baltic countries and Poland with Germany.

Furthermore, Central Europe's leading transport network and major ports are bustling. The EU needs new alternative routes that will help prevent the most challenging transport bottlenecks. A railway connection to the Arctic Ocean could support access to global trade markets via NSR,

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1 A concept of transportation connection between the Arctic Ocean and mainland Europe (<https://arcticcorridor.fi/>).

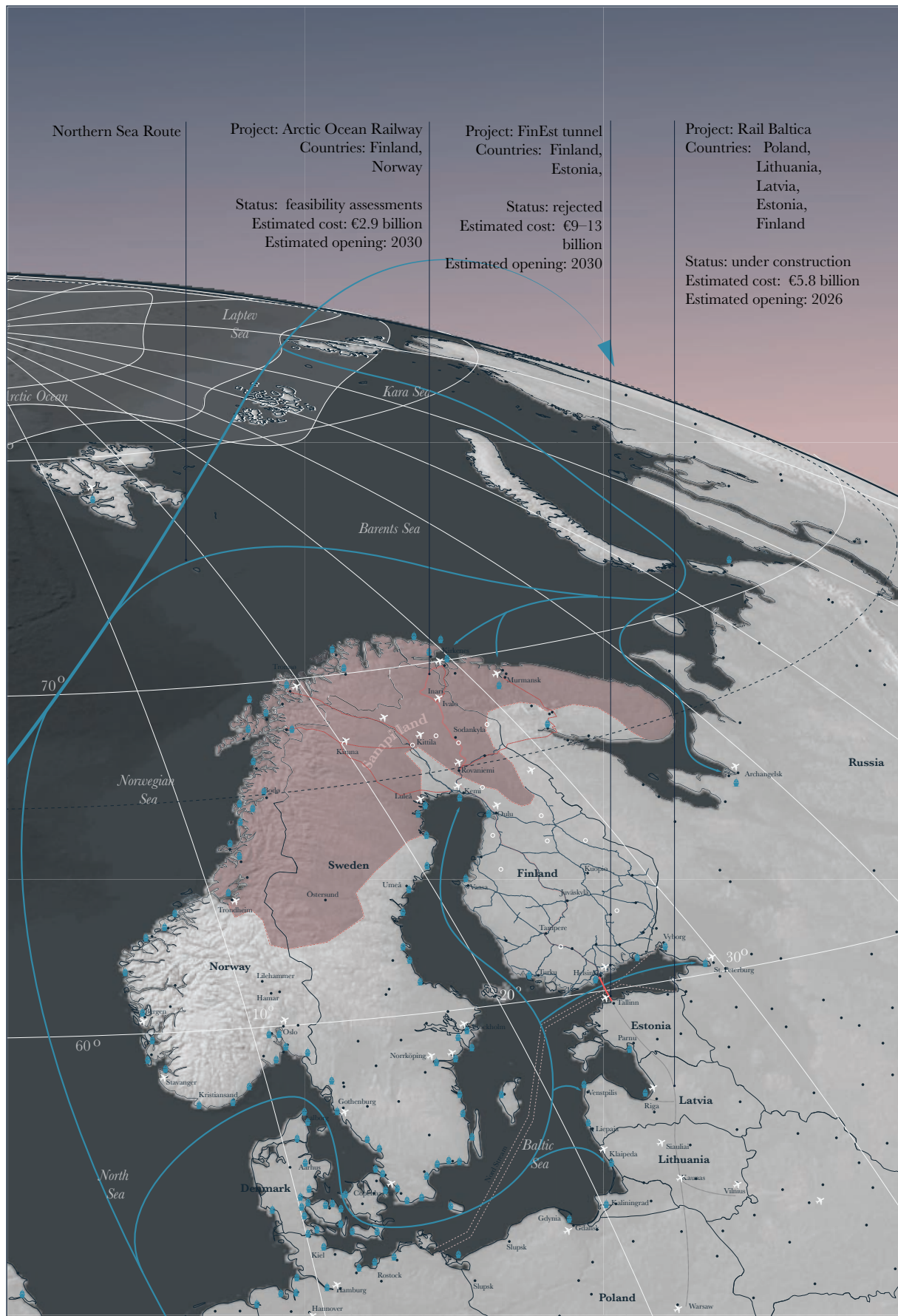
2 The latest record of the project's status is a setback from the Finnish and Estonian authorities even after receiving a provisional 15 billion euros in financing from the China's Touchstone Capital Partners, one of the latest investments that would advance China's Belt and Road Initiative (<https://finestbayarea.online/newsroom>).

3 RailBaltica is a railway infrastructure project with the goal to integrate the Baltic states, Poland and, indirectly, Finland, in the European railroad network. Currently, some parts of the railway are finished while others are still under construction (<http://www.railbaltica.org/>).



*Figure 7. Map showing the Arctic Corridor plans in 1923 (Lilja, 2013).*





*Figure 8. Image showing the Arctic Ocean Railway project as a global mobility infrastructure part, including the Northern Sea Route, the Arctic Corridor and Rail Baltica.*

to improve Finland's logistical position and accessibility and connections in Europe as a whole. It would likely transform Finland's logistical position to a Northern European junction of freight and passenger traffic (Finnish Transport Agency, 2018). The project should, therefore, be seen as a part of the development of the comprehensive global transport system.

Currently, access to Northern Lapland exists by road or plane. Therefore, the railroad would offer an alternative and more environmentally friendly transportation option in the region. The project's economic success is considered to largely depend on the amount of cargo flow and careful design solutions related to environmental impact.

In the feasibility report (Finnish Transport Agency, 2018), five different routes were analysed: Rovaniemi–Kirkenes, Kolari–Narvik, Tornio–Narvik, Kolari–Skibotn–Tromsø, and Kemijärvi–Murmansk (see Figure 9). In this thesis work, the presented route is between Kirkenes and Rovaniemi since it has shown the most potential but also concerning impacts on the region.



*Figure 9. Arctic Ocean Railway route alternatives. From left to right: Tornio-Narvik; Kolari-Narvik; Kolari-Tromsø; Kirkenes-Rovaniemi; Kemijärvi-Murmansk.*

### 3.2. Kirkenes – Rovaniemi route

In a globally connected market, Finland is far from central market areas which lead to transport costs having a relatively high impact on the final price of products (Finnish Transport Agency, 2018). Furthermore, the majority of Finland's imports and exports are transported via the Baltic Sea (Ministry of Transport and Communications, 2019). Consolidating these shipments along a single route makes Finland vulnerable in a crisis

situation. Therefore, a rail connection to the Arctic Ocean would improve Finland's supply security. Furthermore, there is no passenger railway link between Southern and Upper Lapland (Finnish Transport Agency, 2018).

Within Finland, the railway would enable a domestic rail connection from Southern Finland to a port in the Arctic Ocean. Such a scenario could create different tourism and mobility patterns in the whole country.

The endpoints of the Arctic Ocean Railway would be Rovaniemi and Kirkenes. Kirkenes is located in the Sør-Varanger Municipality, the far north-eastern part of Norway. The city has a port that plays a vital role in the settlement's development. If the Arctic Ocean Railway would be built, Kirkenes would naturally become a termination point.

Meanwhile, Rovaniemi is one of the highest population centres in Finnish Lapland, having its airport with domestic and international flights and a railway connection to Southern Finland. It is also known for tourist activities. Connecting the primary urban centre with the rest of Lapland would provide better connectivity between the city and the periphery.

The Arctic Ocean Railway is a considerably large-scale project in Finland knowing that the whole Finnish railway system's length is about 6000 km ([www.vr.fi](http://www.vr.fi)) and the total length of the Kirkenes–Rovaniemi route is 465 km. An alternative option to lay tracks on the east side of Lake Inari was also investigated in the feasibility study, but abandoned as almost 60 kilometres of track would have been necessary through the Vätsäri Wilderness Area (Finnish Transport Agency, 2018).

The trip between Kirkenes and Rovaniemi would take approximately 3,5–4 hours. The train track would follow Highway-4, which already works as an attractor for habitation. The most significant settlements along the track are Rovaniemi, Sodankylä, Vuotso, Saariselkä, Ivalo, Inari, Kaamanen, Sevettijärvi and Kirkenes. It would also run through resorts, multiple mines and nature reserves. This route would run through the Pyhänturi and Luosto tourism centres to Sodankylä, bypassing the Sakatti mining area. The track would follow the power-line land corridor between the Loka and Porttipahta Reservoirs to Saariselkä, where it would then run through a long tunnel. The Saariselä–Ivalo section would then again follow Highway-4. There would be almost 40 km of tunnels between Ivalo and Inari, bridges over numerous small lakes after the track continues north-east from Inari (Finnish Transport Agency, 2018). On the Norwegian side, there would be another two tunnels before the track terminates at a new port in Kirkenes. The route in both countries was designed to avoid residential areas, waterways, nature reserves and Natura 2000 areas whenever possible (Norconsult, 2018).

The investment costs for the Rovaniemi–Kirkenes rail connections are close to EUR 2.0–2.3 billion on the Finnish side. However, on the Norwegian side, the investment would be relatively small: EUR 0.85 billion (Norconsult, 2018). Employment needed for railway construction could result in approximately 20500 (Lapland 12000–14 000) new jobs (Finnish Transport Agency, 2018).

Up until now, all forecasts show that this alternative is not profitable. This is because the loads through the railway would be relatively

low and construction of such project in the Nordic climate while technically possible, is challenging and expensive. However, this could change in the future. One large mine or a significant change in the cost of different modes of transport could significantly change the situation. The railway has potential to become an example of socially powerful infrastructure that would serve as a ‘region-forming’ enterprise, dominating many fields of the social, economic and political life of local communities, combining the elements of technological and social engineering. It can work as an agent of social change and the backbone of regional development (Finnish Transport Agency, 2018).

### **3.3. Tourism and passenger transport possibilities**

To be feasible, the railway should have year-round traffic. Beyond the cargo shipping traffic via the Northern Sea Route, as a cornerstone, there would be a need for other traffic, e.g. passenger trains. It would serve the local population that currently do not have rail access to urban centres as well as visiting tourists. Multiple resorts, regional parks and other nature-based destinations are located in the area attracting a high number of tourists (see Figure 10). In the early stages, passenger train would be seasonal, but it is expected in the long run to become an all year round functioning passenger route. While passenger trains likely would circulate during the day times, cargo trains would run on demand.

To run financially viable passenger traffic between Rovaniemi–Kirkenes with two trains in each direction per day would require about 600,000 passengers per annum (one train in each direction per day, about 300,000 passengers annually (Finnish Transport Agency, 2018). Arctic Ocean Railway could benefit the existing passenger traffic as well. The Kirkenes–Rovaniemi alternative has a great potential since up to now Upper Lapland is not connected via the railway network to Southern Finland, e.g. Helsinki.

Furthermore, the railway would go through Norway’s Sør-Varanger Municipality that has about 3,000 inhabitants. There is an air connection from Kirkenes to six places in Norway, as well as, a cruise route from Bergen. Previous transport analyses for passenger transport in Northern Norway indicate that new rail connections could transfer some travel from other means of transportation within the country. However, this potential is modest (Norconsult, 2018).

### **3.4. Resource industry possibilities**

Freight traffic in Northern Finland currently consists of raw timber, metal, paper, pulp, ore concentrate, fish and chemicals (Lapland Chamber of Commerce, 2018). There exist rail connections From Finland to the port of Murmansk in Russia. Therefore, the Arctic Ocean Railway’s potential transport flows can be studied on a number of levels in terms of internal and cross-border agreements.

Finland currently has 10–15 major projects in the pipeline for ei-



ther opening new mines or expanding existing mining operations for mineral and metal extraction (see Figure 11). The most significant projects with regard to transport requirements are Hannukainen iron ore mine (Kolari), Sokli phosphate mine (Savukoski), Suhanko mine (Ranua), Kevitsa mine's expansion (Sodankylä) and Mustavaara mine (Taivalkoski). The Sakatti mine project (Sodankylä) may also have long-term potential. The project is significant for Copper-Nickel-Platinum discovery made by Anglo American. It is still in the exploration phase, and a lot needs to be done before the mine could be developed (Finnish Transport Agency, 2018).

The Hannukainen and Sokli mines hold the most significant transport potential for the Arctic Ocean Railway. The Norwegian mining company Yara is planning to open a phosphate mine in Sokli, in the Savukoski region of Eastern Lapland. The planned operations would encompass the

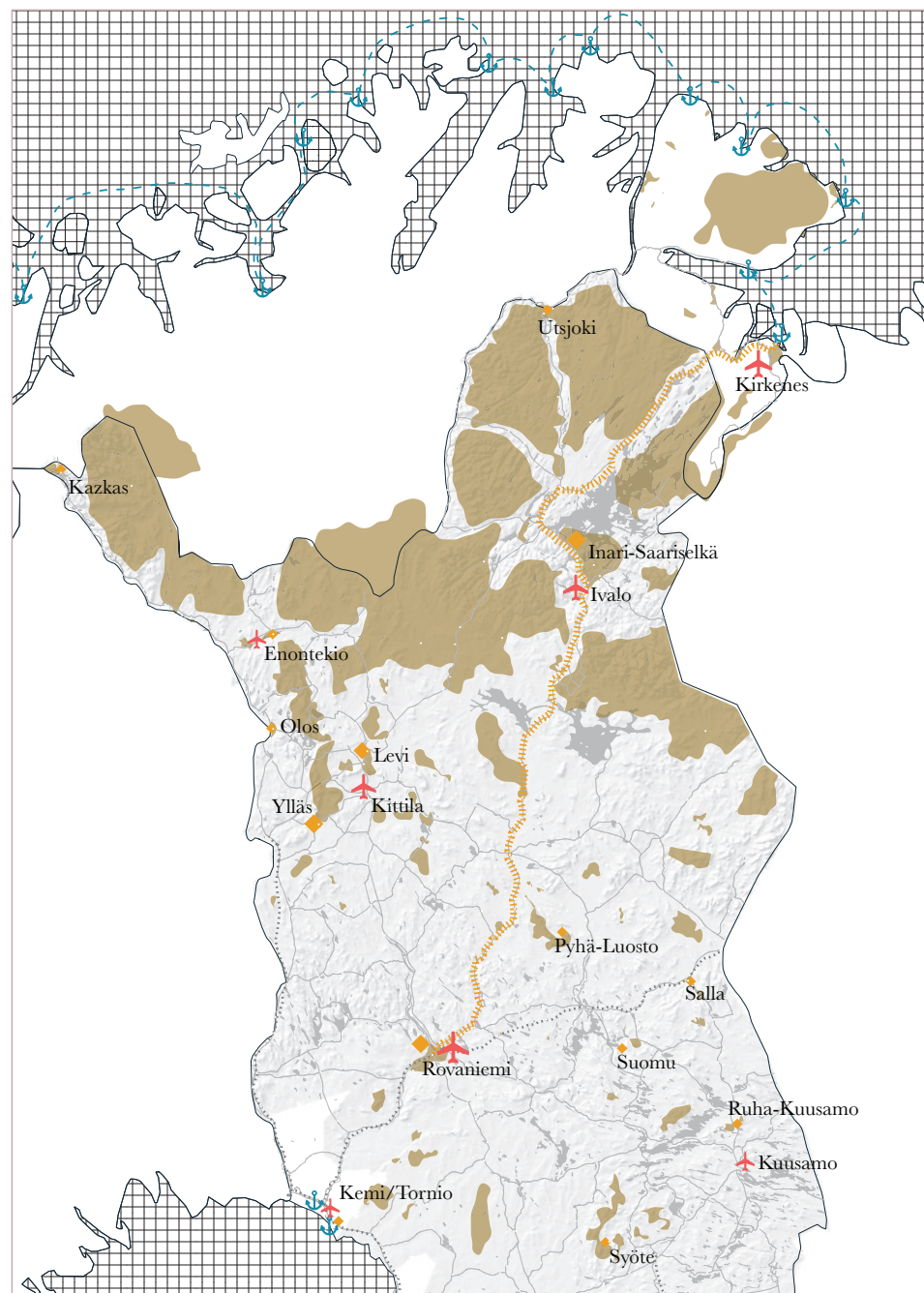
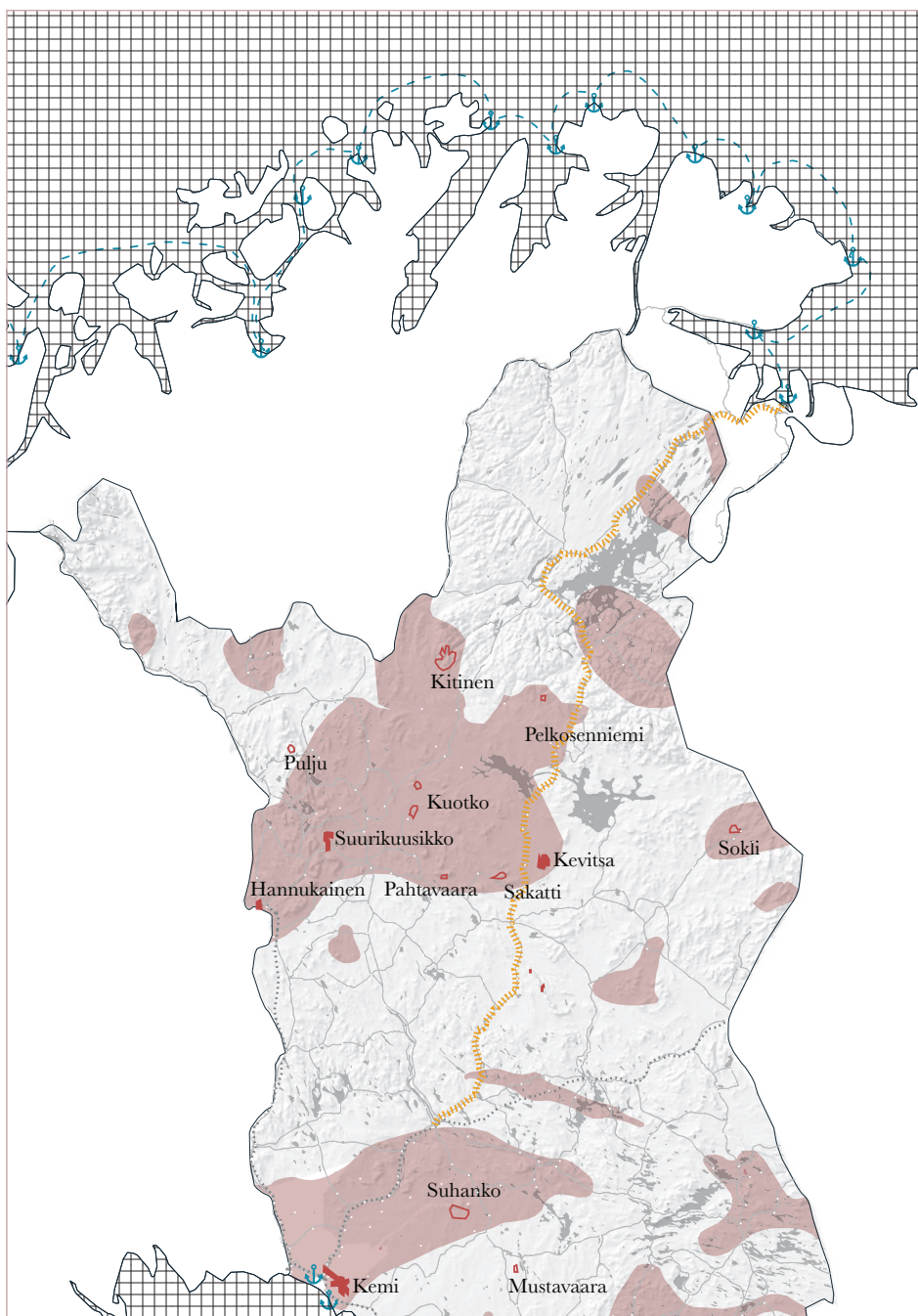


Figure 10. Map portraying tourism destinations in Lapland (resorts and preserved nature areas) colored in yellow and brown respectively, supporting infrastructure and the Arctic Ocean Railway.

mining of phosphate ore and iron mineral reserves. If the mine is opened, the phosphate and iron ore will be enriched in Sokli and transported to Yara's production facilities in Norway for further processing. Therefore, the most likely harbours are Kemi and Oulu. If the Arctic Ocean Railway is built, the ports of Kirkenes and Murmansk would also be options. Using the Port of Kirkenes would be slightly more cost-effective (Finnish Transport Agency, 2018).

The Kevitsa mine is a large copper and nickel mine in Sodankylä. It opened in June 2012 and is owned by the Swedish company Boliden. The mine produces a copper and nickel ore concentrate. All shipments are currently made to Kemi by road. If the Arctic Ocean Railway is built, the mine would have a direct rail link from the mine to Kemi.



◀ *Figure 11. Map portraying the resource potential in Lapland (light red), mines (dark red), supporting infrastructure and the Arctic Ocean Railway.*

A high amount of wood production and its products could be potentially transported via the Arctic Ocean Railway too. The primary product of Boreal Biorefinery's bioproduct mill is softwood pulp. Via the Arctic Ocean Railway and NSR, it would be likely transported to Asian markets. A mainland alternative could also be the Trans-Siberian Railway<sup>1</sup>. It is speculated that if 10% of the combined exports by container from China, Taiwan, South Korea and Japan to the northern European countries would generate more than 37,000 containers per month via the Port of Kirkenes during the 7.4 month-long navigation season. This would, in turn, generate 296 southbound goods trains per month — or approximately ten such trains per day. (Lapland Chamber of Commerce, 2018).

### 3.5. Environmental impact and potential conflicts

In order to curb climate change, more environmentally sustainable solutions and modes of transport become more popular. For tourist traffic, the new, fully electrified railway could have a significant impact on the percentage of people choosing whether to fly or travel by train to the high north of Finland and Norway (Finnish Transport Agency, 2018). Alongside the costs, logistics also consider both energy efficiency and the type of energy to be used, as they will have an impact on how freight traffic is distributed between road and rail transport. As traffic volumes increase, transport choices will also have increasing significance for the environment.

The railway project raises questions regarding the impact and the effect on the Sámi indigenous people as well. The distribution of reindeer owners across Lapland is very uneven (Reindeer Herders' Association, 2014) but the route from Rovaniemi to Kirkenes would go through twelve Sámi reindeer herding districts and split eight (see Figure 12). According to a published interview with the President of the Finnish Sami Parliament, Tiina Sanila-Aikio (Murdoch-Gibson, 2018), this would create serious implications for herding patterns and accelerate landscape fragmentation. From the viewpoint of the reindeer herders, the new connection would restrict the free-roaming of reindeer using the current practice of rotation of pastures. Disturbances in reindeer grazing areas might occur, forcing animals to compete for more food. Together with impacts on reindeer management like the need for new fences or migration routes and noise, it can create severe effects on reindeer health and well-being (Finnish Transport Agency, 2018).

Potential changes might occur in reindeer grazing impacting commercial meat production and slaughterhouse income, thereby reducing the profitability of the industry. This is because due land fragmentation reindeer might compete for pasture more, which requires extra fodder in the winter. This would likely raise costs and lower profitability.

The rail track might also increase the risk of traffic accidents (Ministry of Transport and Communications, 2019). There are known many incidents about killed reindeer along the railways due to poor maintenance or the absence of protective fences as a part of the railway infrastructure.

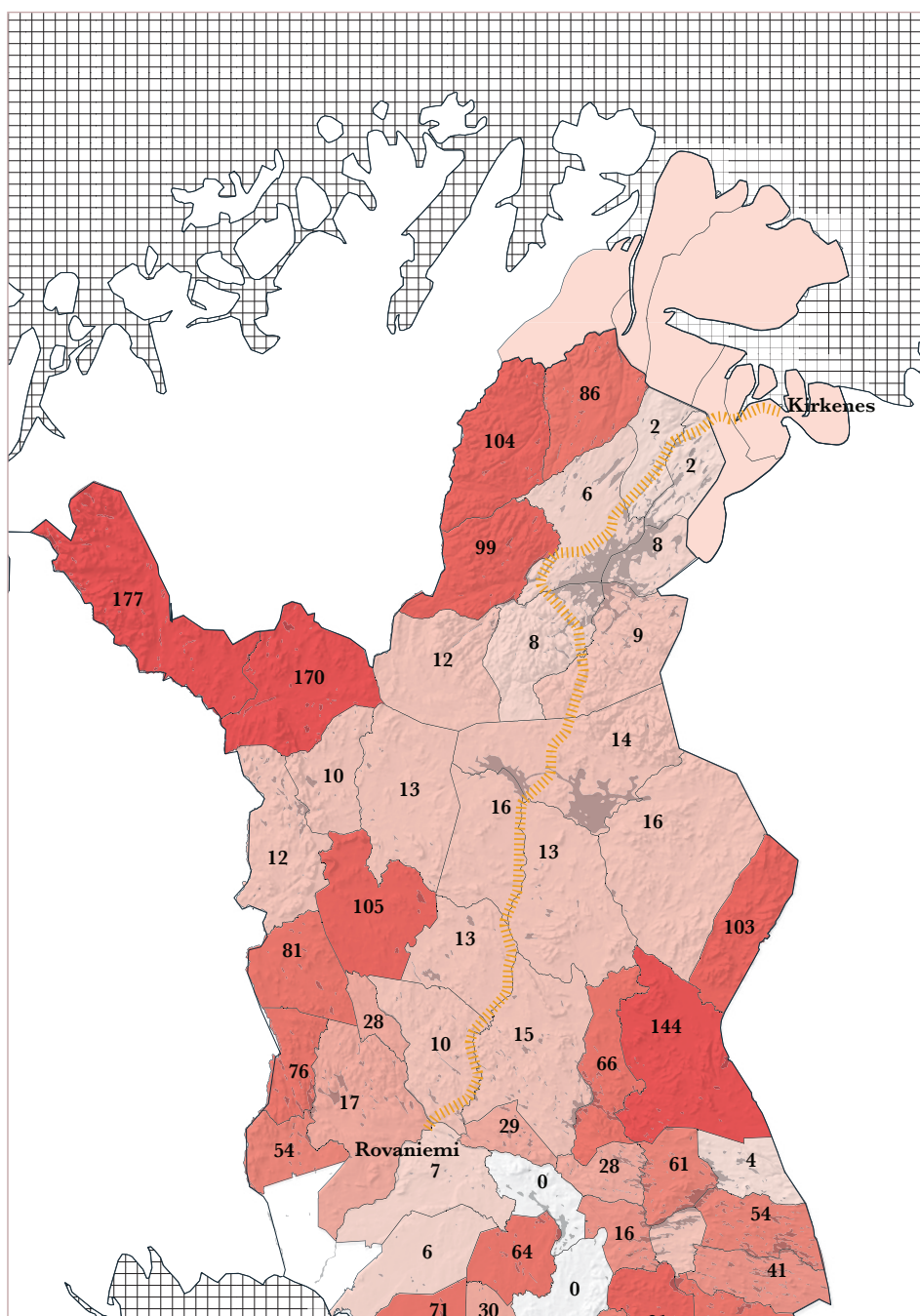
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<sup>1</sup> <https://www.lapland.fi/uploads/2019/10/c9834acc-arctic-railway.pdf>

In an earlier mentioned interview (Murdoch-Gibson, 2018), the President of the Sami Parliament said that there might be as many as 20-50 reindeers killed at once (based on examples from Norway and Sweden). Such accidents can usually have a strong effect on the herders' income.

At this stage, the Arctic Ocean Railway cost calculations have already accounted for the construction of fences along the entire length of the line to prevent accidents involving reindeer. Increased traffic along track sections that are already in existence or under development will also exacerbate adverse environmental factors, such as noise pollution. Additionally, the creation of such a corridor opens possibilities for invasive species influx.

Protected areas account for about half of the area of Northern Lapland, and 38% of Tunturi Lapland (Fell Lapland). The most extensive



◀ *Figure 12. Map portraying herding cooperative boundaries, reindeer distribution (represented by color intensity of the reindeer cooperative and a number of herders) in Lapland and the Arctic Ocean Railway.*



protected areas are wilderness areas and nature reserves. The proposed railway route would go through several such areas in Lapland. For example, the track section between Sodankylä and Näämämä has been planned to run through a zone that lies between extensive protected areas. Lake Inari is part of Finland's national shore conservation programme. The track passes the lake at a distance that should be sufficiently far away to have no direct impact on the area. The area between Sevetijärvi and Näämämö has the highest amount of lakes in Finland, which must be taken into consideration at later planning stages (Finnish Transport Agency, 2018).

The corridor comes close to cultural heritage sites and areas of cultural significance in Norway as well. For example, the route is in proximity to important sites near the Munk river. In addition, sites of archaeological findings and cultural heritage are clustered around Høybukta and Kirkenes in the whole peninsula. Neiden and the surrounding area is especially important for the Skolt Sami population and heritage in Norway (Norconsult, 2018).

Finally, insensitive planning decisions may have tremendous implications on nature, since good connectivity provokes other kinds of activities. Protected, environmentally and historically rich zones have a significant impact on nature-based tourism in Lapland, attracting tourists — potential users of the new railway.

The Arctic Ocean Railway project, which would traverse the Finnish and Norwegian jurisdictions, as well as, the Sámi homelands, has exposed the issue of the absence of a uniform understanding of the state's obligation to consult with indigenous peoples.

# Chapter 3

## *Reflections*

*The Arctic Ocean Railway is a complex spatial construct, both environmentally, ethically, technically and economically. On the one hand, the project sounds like a natural expansion of the global mobility network, creating a connection between the Arctic Ocean and mainland Europe. On the other hand, the impact on local environment and the project's complex nature makes it difficult to assess, halting and questioning its development process altogether.*

*Clear challenges are visible in the project implementation: collaboration among different stakeholders, estimating the environmental implications and economic feasibility.*

*Therefore, the spatial analysis methodology needs to be able to include and evaluate multiple relations the project has with different fields and stakeholders.*



# Chapter 4

## *Intro*

*This chapter introduces the thesis' theoretical framework — Systems Thinking and dynamic patterns.*

*Essential features and definitions of Systems Thinking are presented in this chapter. Furthermore, it is critically evaluated as a way to approach complex contexts, like the Finnish Lapland and the Arctic Ocean Railway project.*

*This chapter also presents examples of the use of systemic thinking and looking at patterns in urban planning and design context. Attention is also given to the meaning of time and direction patterns occurring among the Finnish Lapland system parts.*

*Finally, the chapter introduces the thesis' strategy to approach the case study.*

## 4. From systems to patterns and back

### 4.1. Systems Thinking

*“In a certain sense, it can be said that the notion of system is as old as European philosophy. <...> Man in early culture, and even primitives of today, experience themselves as being “thrown” into a hostile world, governed by chaotic and incomprehensible demonic forces <...> Philosophy and its descendant, science, was born when the early Greeks learned to consider or find, in the experienced world, an order or kosmos which was intelligible and, hence, controllable by thought and rational action.”*

— Ludwig von Bertalanffy (1972)

The three decades after World War II were the grand era for developing unified systems theory due to advances in communications, operations research and cybernetics (Orr, 2014). It was persuasively discussed by Kenneth Boulding, James G. Miller, Ludwig von Bertalanffy, C. West Churchman, Herbert A. Simon, Erwin Laszlo, Jay Forester, Dennis and Donella Meadows, Peter Senge and others.

Donella H. Meadows defines a system as “[...] a set of elements or parts that is coherently organised and interconnected in a pattern or structure that produces a unique set of behaviours [...]” (Meadows, 2008). A holistic approach to systems that derives from a General Systems Theory<sup>1</sup> is known as Systems Thinking. It offers a different approach than the Cartesian paradigm and reductionist thinking. The latter is characterised by the belief that the behaviour of the whole can be understood entirely from the properties of its parts.

Problem-solving and analytic understanding of complex real-world systems is the main focus in Systems Thinking. One of the reasons to be interested in systems is a growing need to understand why events occur in the real world, how to shift it to more desirable directions and identify the problem roots (Meadows, 2008). In other words, Systems Thinking is about creating a sense-making framework to influence future decisions. Because Systems Thinking is generic and relatively independent from the domain theory, it can be instrumental when attempting to make sense of highly complex systems that cover multiple fields with different worldviews (Batty, 2013; Perdicoúlis, 2010). However, it is fundamental to recognize the different worldviews or mental models, when using Systems Thinking to approach urban planning problems (Perdicoúlis, 2010).

While the vocabulary of Systems Thinking is broad, the most important concepts are:

stocks: elements of a system that one can see or measure at any

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<sup>1</sup> The General Systems Theory outlined by biologist Ludwig von Bertalanffy over multiple decades due to independency from domain found role in multiple disciplines ([https://monoskop.org/images/7/77/Von\\_Bertalanffy\\_Ludwig\\_General\\_System\\_Theory\\_1968.pdf](https://monoskop.org/images/7/77/Von_Bertalanffy_Ludwig_General_System_Theory_1968.pdf))

time;

flows: the dynamic process of moving stocks;

drivers: a natural or human-induced factor that causes a change;

feedback loops: a consistent behaviour pattern that emerges when changes in stock affect the stock flows;

self-organisation: a capacity of a system to make its own structure more complex;

interconnections - regulations, requirements (Meadows, 2008).

In the real world, different actors make interaction with physical and organisational structures of society. By understanding these interactions, we gain a better knowledge of the complexity of the system and realise how to influence the system components for desired behaviour and outcomes (Meadows, 2008). Micheal Batty presents a similar systematic approach to spatial analysis, city and urban planning. He states that all localities are built on interactions and what happens in locations is a synthesis of how different activities interact with each other (2013).

Analysing systems can help to improve planning processes in a globally challenged world. For example, observing the correlations between more significant storms and prolonged droughts, global warming, supply disruptions and economic turmoil can improve the city's as a system preparedness. This can be achieved through building codes, urban planning and design, mobility management, economic development, taxation, emergency preparedness and many other aspects that urban world consists of (Merali & Allen, 2011).

One of the early examples of Systems Thinking and system model application in urban planning and design tasks is Jay W. Forrester's simulation model presented in his book *"Urban Dynamics"* (1969). His main goal was to develop a tool that could be used by urban policymakers and to study the processes underlying the development, stagnation, decline and recovery of cities (Lane & Sterman, 2011). The repetitive use of computer simulations allowed Forrester to analyse essential factors like population, housing distribution, and how its changes would affect the city growth. By introducing time dimension, he has shown that urban change and planning decisions had an often counterintuitive quality (Batty, 1971). This example is also important as it manifested the human's ability to abstract and simplify and the computer's ability to deal with complexity over time.

### *System structure*

Knowledge of a system structure and operating rules helps to understand the causes of specific processes in the system better. For example, it can help to improve resilience in a rapidly warming world, and perhaps anticipate counterintuitive outcomes that would, otherwise, come as surprises. Therefore, systems structure can be identified as a manner in which a system's elements are organised or interrelated (Kim, 1999). Systems that work well usually have these characteristics: resilience, self-organisation and hierarchy (Meadows, 2008).

Apart from earlier mentioned system parts (stocks, flows, feedback loops and drivers) other elements can be found as system's structural components. To mention a few:

**Controlling variable:** a system component that has a dominant influence on the functioning of the system. Often, these are slowly changing components that trigger fast changes in other variables (Meadows, 2008).

**Resilience:** system resilience shows its ability to survive changes and fluctuations in their environment. Resilient systems are, however, not constant but very dynamic — there is a distinction between static stability and resilience.

**Hierarchy:** the original purpose of a hierarchy is always to help its originating subsystems to perform their jobs better. Hierarchical systems usually evolve from the bottom up. The purpose of the upper layers is to serve the lower layers of the hierarchy.

**Regime shift:** a substantial and enduring reorganisation of the system, where the internal dynamics and the extent of feedbacks undergo irreversible change (Arctic Council, 2016).

**Leverage points:** defines parts in the system, that can significantly shift the system's behaviour due to a small change (Meadows, 2008). It can be seen as a point of power. However, those leverage points usually are counterintuitive.

**Tipping point:** A specific kind of threshold, often recognised in systems that show oscillations between alternative states (Arctic Council, 2016).

**Adaptive capacity:** the ability of a system or individual to adjust to changing conditions or recover from the impacts of change. In ecological systems, adaptive capacity is influenced by the biodiversity and the degree of redundancy in the system. In social systems, it is determined by the structures and processes that enable or constrain choices for action and that shape people's ability to anticipate and plan for future change.

### *System behaviour*

The system structure is the source of system behaviour. It reveals itself as a series of events over time that forms patterns and spans all scales and forms, e.g. it can be a train schedule or a heartbeat. Also, it represents the notion that a system such as a city or a region is not something that is planned from the top to down but rather emerges organically (Batty, 2013).

Each system can be explained through its behaviour. Furthermore, by studying system behaviour, one can investigate how systems can produce problems without the intention to do it. Therefore, observation is a crucial step before disturbing the system. Detecting causes that form certain system behaviour is basis for designing an intervention in the system's structure (Diemer & Nedelciu, 2020).

An essential part of system behaviour is the feedback loops. It can be seen when one event produces another event. Some feedback events balance the system, others reinforce specific behavioural trajectory and both shape patterns.

## 4.2. Patterns

*“Leading us away from the system of fixed things, and toward the system of spatio-temporal patterns, the newly revealed visible world brings us to the threshold of a new vision”*

— György Kepes (1956)

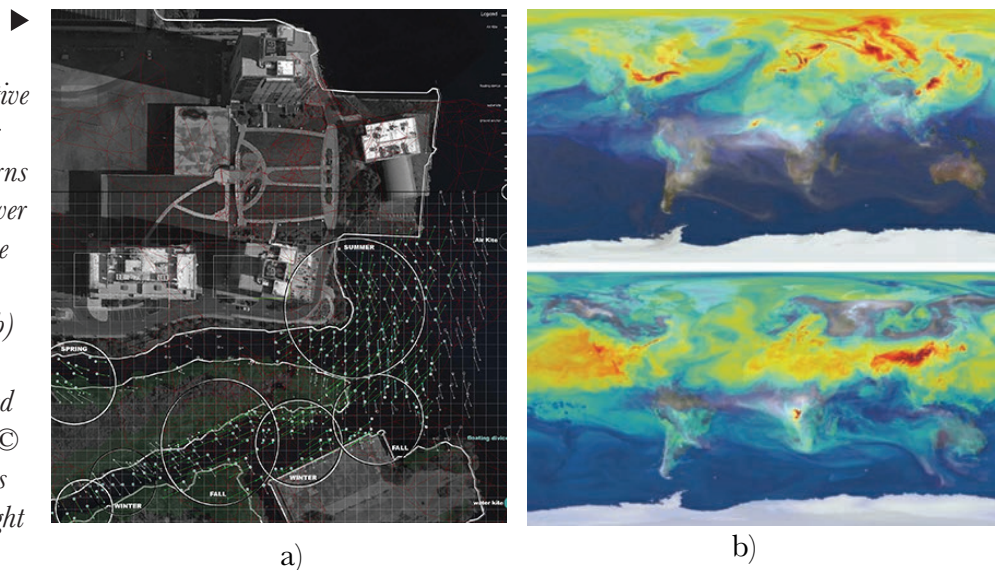
Patterns can be defined as relational frameworks that simultaneously describe and project: they reveal structures, processes, and relationships, as well as it structures the physical elements that give shape and form to our world. They do not exist as entities themselves but only in relations between or among things (M’Closkey & VanDerSys, 2017). Patterns can be one way of approaching complex systems and show different characteristics over time.

Two pattern types were introduced in this thesis framework: accretive and behavioral. While they have different characteristics, within this thesis they are strongly intertwined.

Accretive patterns describe processes, like movements, transformations and actions upon a surface. They are commonly used to simulate behaviours, like air or hydrological flows, or to depict transitions in environment arising from forces, like direction or intensity (M’Closkey & VanDerSys, 2017). Furthermore, because accretive patterns deal with movement and change, they can be mapped over different time frames, thereby revealing other patterns through comparative analysis. Additionally, since this type of pattern deals with movements and aggregation, it is best expressed through fields of intensity (see Figure 13 a)).

Behavioral patterns can bridge scales by linking the behavior of physical and abstract systems in time and space (M’Closkey & VanDerSys, 2017). Therefore, they well manifest Systems Thinking. These patterns find their use in creating an environment with which other environments can be explained or evaluated. For example, simulations of global heat waves help to explain linkages of temperature changes in different locations and how they are formed. In other words, they are made visible through infor-

*Figure 13. a) accretive pattern - changing air and water patterns in the Delaware River © Courtesy of Elise McCurley, Leeju Kang, Chris Arth; b) behavioural pattern - heatwaves captured by satallite sensors © Courtesy of NASA’s Goddard Space Flight Center.*



mation and communication technologies (see Figure 13 b)). Thus, a key aspect of these types of patterns is that they cannot be seen by the human eye but only through a technological medium, like motion and heat sensors or satellites to capture the data (M'Closkey & VanDerSys, 2017).

Using Systems Thinking and analyzing patterns can empower the designers to curate the design process by developing greater insight into where they can have agency and impact (Walliss & Rahmain, 2018). Therefore, reoccurring patterns in various phenomena can become the very material that shapes it (Cantrell & Mekies, 2018). This ability to define the point of intervention temporally and spatially is particularly meaningful when engaging with dynamic systems such as Finnish Lapland. Computer scientist Chris Leckie defines this as a 'high value' problem. He comments that unlimited access to data demands a high level of critical thinking. It requires to 'pick out the interesting or unusual events that are worth exploring and then filter them down to high-value problems' (Leckie, 2013).

In Chapter 7 and 8, visual pattern representation is established through dynamic video clips or snapshot images of a running simulation. Such a representation is an attempt to understand the Arctic system beyond two-dimensional representations like mapping.

#### **4.3. The Arctic region within Systems Thinking**

Initially, it might seem difficult to draw a boundary of the Arctic region and where one system ends, and another starts. However, there are no separate systems. It is even more likely that systems are embedded within other systems. Where to draw a boundary around a system depends on the purpose of the discussion. System boundaries are imaginary, therefore, they can and should be reconsidered for each new discussion, problem, or purpose (Meadows, 2008).

Chapter 2 and 3 introduce some characteristics of the Arctic region and the chosen study case — the Arctic Ocean Railway project. From these chapters, it is visible that the Finnish Lapland — is a highly complex and dynamic system. It consists of multiple connected subsystems, like reindeer herding, tourism, resources or shipping (see Figure 14). There exist stocks of resources and population, drivers like global and local demands, feedback loops, e.g. increasing annual temperature provokes permafrost thaw.

One can also notice appearing regime shifts: melting sea ice might completely change shipping future in the Arctic Ocean. The improved accessibility due to Arctic sea ice loss may lead to exploitation of Arctic fossil fuel reserves, thereby producing more greenhouse gasses and accelerating warming, is an example of amplifying feedback in the region as well.

#### **4.4. The spatial meaning of time and direction in the Arctic system**

*“Only when a system behaves in a sufficiently random way the difference between past and future, and therefore irreversibility, enter into its description... The arrow of time is the manifestation of the fact that the future is not given, that, as the French poet Paul*



*Valery emphasized, ‘time is a construction’”*

— Isabelle Stengers and Ilya Prigogine (1984)

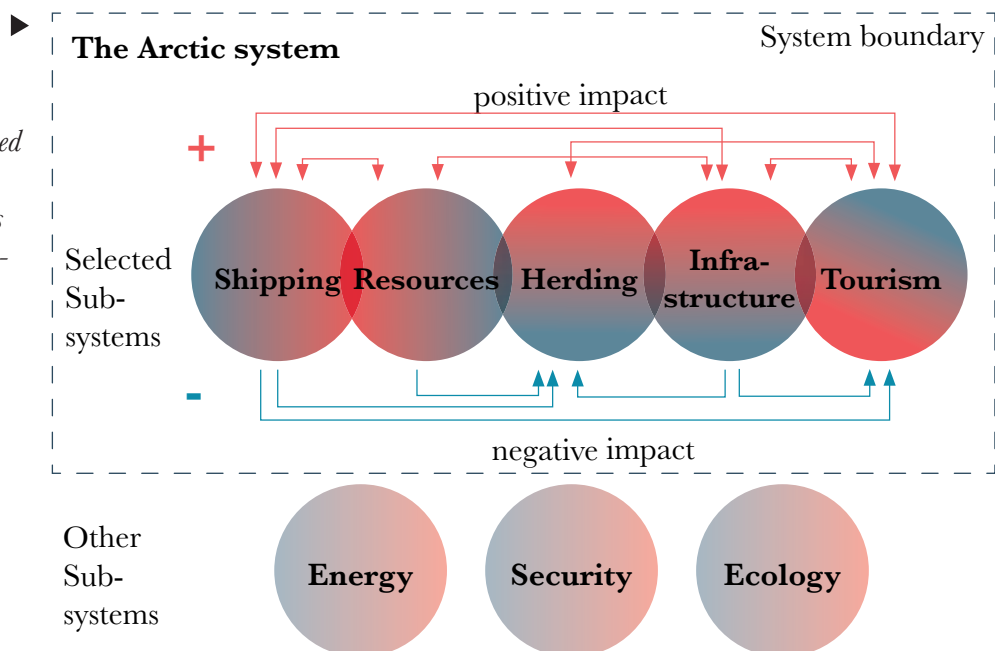
A vast number of slow or fast events, visible or invisible interconnections and interdependencies in the Arctic have been mentioned so far. When looking at it through the lens of Systems Thinking, the subsystems of the Arctic system, like infrastructure, herding or shipping, have some dynamic variables in common. Often, these common variables might uncover the drivers of spatial transformations and can operate across various temporal and spatial scales (Batty, 2013).

In the context of the Arctic system, time and direction are relevant variables as they can be found in all systems of selected spatial narratives.

Infrastructure, shipping, herding, tourism and resources spatial narratives in Finnish Lapland have time variables, i.e. a schedule or a life-cycle. For example, a train moves according to a specific schedule, herds graze and migrate according to their grazing cycle that developed over thousands of years, the tourists land and depart according to a flight schedule, which intensifies in one period of the year and lessens in others. Two examples are presented below to illustrate the relevance of time patterns in spatial analysis.

Different research-driven techniques to respond to heatwaves across Melbourne were explored by the University of Melbourne and RMIT University students. In a project called “Reset Pods” (Bessabava & Szumer, 2015), through the analysis of real-time data collected on-site through sensors, students discovered a pattern in climatic behaviours, where the air temperature at specific locations would significantly drop for an extended period of time despite the overall trend of rising temperatures. Such investigations can impact the material selection, overall design and placement of different mitigation elements in a built environment (Cantrell & Mekies, 2018).

*Figure 14. A diagram portraying the Arctic system: selected sub-systems, other existing sub-systems and general relationships.*



Another project “*Polluted City: A Meteorological Driven Design Approach for Beijing*” (Yu, 2016), this time in Beijing, focused on air pollution. Part of its design was the investigation into which times of year and times of day result in the highest pollution exposure. Bringing these two temporal scales together revealed that air pollution levels reach their highest levels during winter nights and lowest levels are during the day in summer (Cantrell & Mekies, 2018). This example shows how daily behaviour can generate different air pollution experiences. Furthermore, the design can expand from physical pollution mitigation strategies to affecting people’s choice for location and time depending on the air quality.

For a long time, urban and regional transformations were articulated as a continuous, smooth change. However, presented examples show that the nature of actual change is quite different, often discontinuous or irregular (Batty, 2013). Therefore, looking at time patterns in multiple scales allow exploring various non-smooth dynamics, presenting the spatial analysis in animations and simulations.

Both examples and their time-based spatial analysis prove the potential of time patterns in computational design methodologies in planning and urban design tasks. Therefore, it seems self-evident that spatial transformations should be analysed by including time patterns as a determining factor to support decision-making (Moffatt & Kohler, 2008).

Each spatial narrative in Finnish Lapland can be represented through moving and not moving agents that have direction as a variable. For example, trains move from south to north, ships from east to west, herds from winter grazing areas to summer grazing areas, and in an abstracted way, resorts create negative divergence while airports create positive divergence. Therefore, addressing direction is a form of looking at the phenomena through the notion of flows. They can be used to understand spatial potentials, i.e. what entities go in and out from the locations and how (Batty, 2013). These directions, as a variable, can change, creating feedback loops in agents behaviour. The notion of flow and direction is well visualised in a project “*Prophylactic Landscape*” (Lam & Stevenson, 2011) that explored different water flow volumes across the uneven ground surface as a product of slope and water quantity. It allowed estimating where the greatest water volume would collect. Multiple projects involving direction visualisations are also created by PEG office of landscape. For example, in the project “*Simulated Natures UPenn*” by PEG office of landscape, digital “kites” were used to visualise simulated wind flows and show its magnitude and direction. It conceptualises the ecological and social formations by displaying, otherwise invisible, information.

The manipulation of both variables might support the understanding of dynamic behaviours, and most importantly, ease the identification of the design decisions with the highest potential. This approach is best articulated by Keith VanDerSys, who uses modelling to reveal changes in systems where patterns represent processes that have a physical impact (Cantrell & Mekies, 2018). Therefore, these two system defining variables became a point of interest to define and represent the patterns in Finnish Lapland, which are further presented in Chapter 5.

# Chapter 4

## *Reflections*

*Systems Thinking can be seen as a form of observation to better understand the phenomena before actually intervening*

*The boundary of a system is subjective and depends on the one who defines the particular system. Therefore, the same parts can belong to multiple systems, just because the imaginary boundaries divide it.*

*Since patterns in systems are not easily visible, suitable visualisation is crucial in order to benefit from it. By observing patterns, more apparent connections between elements in feedback loops can be defined.*

*Systems Thinking could likely be applied to Finnish Lapland system and the Arctic Ocean Railway project, since there can be found many similarities to the theoretical Systems Thinking models, as well as project examples analysing chosen patterns.*

# Chapter 5

## *Intro*

*This chapter covers the characteristic patterns that can be observed among selected spatial narratives in Finnish Lapland. They are existing or speculative. Each pattern is presented through a brief overview of reasons for its emergence, the main challenges it currently faces and the behaviour. The latter is further parameterized in Chapter 7.*

*The presented patterns are:*

- *Resource pattern - existing*
- *Herding pattern - existing*
- *Infrastructure pattern - speculative*
- *Tourism pattern - existing*
- *Shipping pattern - speculative*

## 5. Arctic Patterns

### 5.1. Mining pattern - existing

One of the most discussed and controversial perspectives on the Lapland region is its natural resources. The mines are essential for the future of the remote regions of Lapland (Suopajarvi, 2015). Recently, interested global community places the Arctic region, including northern Finland, among the most favoured areas for resource extraction activities (Similä & Jokinen, 2018). While the supply of raw materials is ultimately a global issue, mineral extraction can be significantly profitable for the global, local communities and states themselves as it creates jobs, increases migration to the region and boosts tax revenue (Similä & Jokinen, 2018).

Mining communities usually depend on the longevity of mining projects. Therefore, it is crucial to evaluate long-term benefits and threats that a mining project could bring to the region despite of immediate benefit. For example, even after closing the mine's site, it takes years for nature to regenerate and to reestablish valuable attractiveness (Similä & Jokinen, 2018).

The lifespan of a mine consists of four phases: prospecting and exploration, development, extraction, closure-reclamation (ELAW, 2010).

The prospecting and exploration phase can last between two to eight years, depending on the case. This phase involves the sampling process and its impact on the physical area is not intensive.

The development phase usually takes 4-12 years to open an ore deposit for production. During this phase, extensive planning and paperwork are done together with building infrastructure, like roads, and the mine itself, forming a working community around it. The physical impact increases during this phase since the mine covers more space, as well as, it creates additional infrastructure.

During the exploration and development phases, no resources are intensively extracted. On the one hand, the outward flow is minor, and the impact is relatively small. On the other hand, the highest pressure is given on nearby settlements by the inflow of skilled labour population.

During the extraction phase, the mineral is removed from the earth in large quantities. Generally, the extraction phase length depends on the deposit. Mine facilities usually actively extract resources for 5-30 years to complete, but there are known cases where this stage is much longer.

The closure and reclamation phase starts early of the mine's life cycle. The initiation of the closure phase results in shrinking the impact area from the mine (ELAW, 2010).

The amount of jobs a new mine will create is crucial for mining success, reputation and acceptance. Many jobs might be created directly in the mining facility, but there is also indirect employment which supports the industry. The number of jobs also correlates with the mine's phase: it actively increases in development and extraction phases. When opening a new mine, the pressure is likely to appear on housing, and in particular,

the need for rental apartments. With a new population, demands grow for services such as children's daycare centres and schools, occupational health care, sport and leisure time activities, as well as, an increase in construction licensing (Moritz et al., 2017). Critics claim that the benefits of resource extraction will not stay within the region. Hence, local people will become increasingly dependent on decisions made outside the region (Nordic Council of Ministers, 2015).

The relationship between mining and tourism differs. It depends on factors such as the locations of activities, landscape and types of mining or tourism. A tourist resort located nearby a mine may benefit from mining community using its services. Furthermore, mining in remote locations often improves accessibility, since a good infrastructure is a precondition in resource extraction projects. Finally, mine's vicinity to a tourism destination and its services might make mining jobs more attractive to potential employees (Similä & Jokinen, 2018). For example, Boliden Kevitsa was opened in 2012 and currently offers direct jobs for more than 400 people, more than 700, if counting subcontractors. They become attractive clients for tourism businesses, reinforcing each other. Such situations help to balance the unemployment rate in Lapland, as well as, provide traditional livelihoods with additional income.

While tourism and mining industry that co-exist in the near vicinity can benefit each other, mining affects tourism in more negative ways than vice versa. A new mine might drastically affect nature and landscape, therefore, reducing the attractiveness of a tourism destination (Similä & Jokinen, 2018).

Furthermore, mining projects usually sharply conflict with local communities and show little sensitivity to existing ecologies, cultural traditions and lifestyles, which it affects, e.g. reindeer herding (Stephen, 2018). While reindeer herding and mineral extraction are both regarded as national interests, they typically compete for land-use rights. Additionally, by-products of mining practices can impact the environment with toxic waste or dust covering vegetation.

Despite the possible threat imposed by mining on Sami culture and heritage, the mining industry might be beneficial for the community as well. For instance, it would provide the possibility for young Sami to stay in their home area rather than moving to cities in order to secure a living (Koivurova, Masloboev, et al., 2015).

## **5.2. Herding pattern - existing**

Reindeer husbandry is a distinctive activity of the only Indigenous People group in Europe – Sami. Being able to continue reindeer husbandry is an essential part of their culture and heritage. In the past, herders had extensive availability to the local lands, but now, more different agents in the region have to share the same territory. This naturally affects the reindeer numbers and whole Sami livelihoods.

In Finland, reindeer husbandry is divided by area into units of varying sizes called reindeer herding cooperatives. It is a community com-





SODANKYLÄ

Jul



prised of reindeer owners. There are 56 reindeer herding cooperatives in Finland's reindeer herding area with varying numbers of herd owners. Reindeer cannot migrate from one cooperative to another due to enforced fences.

The maximum permissible number of reindeer livestock for the reindeer herding area in Finland for the 2010 – 2020 term has been specified as 203,700 heads (The Ministry of Agriculture and Forestry). Climate conditions and available land strongly influence this number.

The distinct herding pattern is visible in the reindeer grazing cycle. Following their natural rhythm, reindeer graze in different grazing areas during different times of the year. The reindeer year begins in May or June when the calves are born. It is when the overall reindeer population increases dramatically. The calving areas are usually the (southern) slopes of fells and hills with little snow cover or the bog regions, from which snow thaws earlier. Once the calves are healthy enough, spring migration starts and lasts from a few days to a few weeks (Reindeer Herder's Association, 2014).

The summer grazing areas are nutrient-rich bogs, open felling areas, stream front meadows and open fell highlands. Midsummer is a time when reindeers often drift into open mine pits, railway tracks and roads due to wind conditions unfavourable for insects.

In the autumn, the reindeer traverse forests and fell heathlands, particularly for seeking mushrooms, which contain an abundance of nutrition. A notable decrease in reindeer heads happens in September when reindeers are slaughtered for domestic or commercial use. Reindeer begin their mating season at the end of September. After the mating period, reindeer herds are usually divided into smaller herds for winter grazing migration. Smaller herds also reduce competition for lichen.

In the winter, the most important source of energy for the reindeer is lichen which it digs up from beneath the snow. Snow is usually lighter in highlands and mountain tops. Winter pastures are regarded as a minimum factor in reindeer husbandry. The number and condition of these pastures determine the survival of reindeer through the winter.

There are behavioural differences between the sexes in the disturbances to reindeer pastures. The female reindeer tend to avoid infrastructure project areas more than male reindeer. Male reindeers have less sensitivity to noise disturbance. In addition, the behaviour of reindeer is also affected by the size of the herd — large herds can endure more disturbance (Reimers & Coleman 2009).

Due to climate change, Arctic winters get shorter and less predictable, causing changes in reindeer behaviour. According to The Natural Resources Institute Finland (Luke), reindeer herds decide when to start the migration and how fast to move, based on spring weather and depth of snow.

Expanding the eco-tourism industry in Lapland has a strong impact on reindeer herding. Since reindeers are an inseparable part from Finnish Lapland, it is also a popular tourist attraction. The potential growth in demand for services related to reindeer meat, reindeer handicrafts or rein-



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deer-related services, could benefit the reindeer community.

Mining exploration promoted by the national governments has long been a source of conflict with Sami interests. It has detrimentally impacted herd mobility by taking away grazing land and by interfering in migration routes (Tysiachniouk & Olimpieva, 2019). For example, the gold excavation companies claim that the environment will revert to healthy pasturage for reindeer ten years after mining activity has ended. The Natural Resources Institute Finland (Luke) says that this estimate is far too optimistic. A full mine's territory reclamation by nature might take multiple decades to recover from gold mining. Because of increased competition for food, more stress and the increased wearing of pastures, the reindeers gain less weight until slaughtering. This impacts the meat production, slaughter income and weaken the viability of the Sami livelihood.

Tourism, mining and other human activity also increase heavy vehicles traffic numbers on the roads in the north. The majority of road traffic accidents with reindeer occur in November–December in dark and slippery conditions, which usually leads to the loss of breeding animals over the winter. Most of the reindeer accidents on railways occur in mid-winter and mid-summer. In the winter, when the snow cover is thick and soft, reindeer can easily walk along railway tracks. In mid-summer, during the periods of insect swarms, the reindeer often seek refuge from insect harassment by moving to windy railway embankments situated higher than the surroundings (Jernsletten & Klovov, 2002).

The biggest challenge for the endurance of reindeer husbandry throughout the world is the loss of pastures, which in Fennoscandia is mainly affected by the expanding infrastructure and other forms of land use (Jernsletten & Klovov, 2002). Losses of pastures usually occur in a broader area than merely what infrastructure covers, which reindeer and reindeer husbandry can no longer use.

### **5.3. Infrastructure pattern - speculative**

Infrastructure pattern emerges from the need of better global connectivity to ensure national security, improve transport capacity, support boosting industries and businesses in the region, like tourism and resource extraction, and to assist the basic needs of remote communities through better accessibility.

The Arctic Ocean Railway should be seen as part of the global transport system. In the north, it would connect with the Arctic Ocean and to the south with the possible Helsinki-Tallinn Tunnel and Rail Baltica, connecting Continental Europe with the Arctic Ocean, as well as, Europe and Asia.

If the Arctic Ocean Railway is going to be economically sustainable, it must have traffic that provides year-round activity. Beyond the cargo shipping traffic via the Northern Sea Route, as a cornerstone, there would be a need for other traffic when shipping is not available due to snow accumulation in the Arctic Ocean.

The Arctic Ocean Railway train would take approximately 3.5 -



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4 hours to travel the distance between Kirkenes and Rovaniemi without counting stopping and loading/unloading times. The trip duration depends on weather conditions, type of the train (passenger or freight), allowed speed, weight, number of stops along the route and stop duration. In the early stages, tourism passenger trains would be seasonal, but it is expected it would become an all year round functioning passenger route in the long run (Finnish Transport Agency, 2018). Furthermore, by being more environmentally friendly transportation mode than flights, the train might take over a portion of the domestic plane passengers. While passenger trains likely would circulate during the day times, cargo trains would run on demand.

The railway track would follow Highway-4, which is already an attractor for habitation. The most significant habitation clusters along the track are Rovaniemi, Sodankylä, Vuotso, Saariselkä, Ivalo, Inari, Kaamanen, Sevettijärvi and Kirkenes. The route would also run through resorts, multiple mines and nature reserves. Running financially viable passenger traffic between Rovaniemi– Kirkenes with two trains in each direction per day would require about 600,000 passengers per annum (one train in each direction per day, about 300,000 passengers per annum) (Finnish Transport Agency, 2018).

The existing reports estimate that freight transportation on the Arctic Ocean Railway would mainly include minerals, fish products, raw wood and wood industry products. It is speculated that 10% of the combined exports by container from China, Taiwan, South Korea and Japan to the northern European countries would generate more than 37,000 containers per month via the Port of Kirkenes during the 7.4 month-long navigation season. This would generate approximately 296 southbound, 750 meters long goods trains per month or ten such trains per day (Lapland Chamber of Commerce, 2018).

However, the route would create severe implications for herding patterns and cause landscape fragmentation (Sanila-Aikio, 2018). According to herders, the new connection would restrict the free-roaming of reindeer. The rail track might also increase the risk of traffic accidents involving reindeer (Ministry of Transport and Communications, 2019).

#### **5.4. Shipping pattern - speculative**

As sea ice decreases in the Arctic, expectations for a commercially feasible Arctic shipping route are rising (Farré et al., 2014). Climate change is the main driver making the Northern Sea Route (NSR) as a connection between Europe and Asia relevant. The increasing globalization shifts the focus of international trade and production towards Asia. This is why improved connections to Asia are becoming more relevant to Europe as a whole. The current volume of goods transported via the NSR is modest, but the growth can be observed every year (Ministry of Transport and Communications, 2019).

The reduction of summer sea-ice is likely to extend, allowing to navigate the Arctic Ocean already by mid-century (Koivurova et al., 2014).

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Since the route would reduce travelling time and used fuels, it naturally attracts everyone's attention. The emerging NSR also gives more incentives for port developments along the route, e.g. Sabetta port, Kirkenes port.

Currently, shipping pattern is speculative, since many of its possibilities are still in the future plans and are not implemented. Based on 2016 figures, 10% of the combined exports by container from China, Taiwan, South Korea and Japan to the northern European countries of Germany, Denmark, Finland, Sweden and Norway would constitute 275,000 containers per year. This could generate more than 37,000 containers per month via the Port of Kirkenes during the 7.4 month-long navigation season (Lapland Chamber of Commerce, 2018). Further decrease in sea ice would likely rise these numbers even higher.

The shipping pattern also covers the existing cruise shipping in the Arctic Ocean mainly operated by the Norwegian company Hurtigruten<sup>1</sup>. The cruise route from Bergen to Kirkenes stops at 34 ports along the Norwegian coastline. The number of passengers depends on the ship type and can vary from 300 to 600. The daily journey from Bergen to Kirkenes takes six days, where arrival time in Kirkenes is at 09:00 and departure southbound to Bergen is at 12:30.

There are existing plans to extend the Bergen–Kirkenes route to Murmansk as the terminal stop. The route would then become a vital Northern tourism artery in the Arctic region.

Marine traffic is expected to increase in future years, but Arctic shipping still has many obstacles to overcome to make this route feasible and less environmentally questionable (Stephen, 2018). Container ships operate under a just-in-time system, which relies on precise schedules for loading, shipping, and unloading to maximize the efficiency of logistics and push costs down. Therefore, the mentioned risks and unpredictability still keep important investors and industry representatives sceptical (Stephenson et al., 2014).

### **5.5. Tourism Pattern - existing**

Since the 1980s, tourism in Lapland has been the fastest-growing private sector industry. The growth within the tourism industry has been most rapid in the tourism services, like skiing, during the winter season. Therefore, tourist distribution mainly spread across areas with suitable slopes (Rantala & Valkonen, 2011).

Lapland tourism is also nature-based and anchored in the quality of the pristine local environment, which is the main reason for travelling to the region (Similä & Jokinen, 2018). It is a business that is dependent on an image that sells (Pashkevich, 2014). Usually, tourism destinations have central attraction entities, like resorts. For example, within the municipality of Kolari, tourism is firmly concentrated at the Ylläs tourist destination, which is adjacent to Finland's most famous national park, Pallas-Yllästunturi.

Tourism had the most significant boost in 2017 with 9% growth

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<sup>1</sup> [www.global.hurtigruten.com](http://www.global.hurtigruten.com)





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compared with the previous year. The total amount of registered overnight stays was over 2,9 million<sup>1</sup>. For the first-time, international tourists had a majority in overnight stays in Lapland with 51% in 2017. It illustrates the short term population inflow into the area that at the moment is depended on seasons, but round year inflow is foreseen in the future. Tourism is highly interdependent with road, railway and airport infrastructures since an attractive tourist destination needs functional connectivity for visitors to reach it.

The tourism pattern in Finnish Lapland can be defined by flight schedules and incoming and leaving population distribution in the area over the year. Most of the tourist population arrives and leaves by plane, where the final destination usually is a nearby resort or a settlement that has a convenient transportation network. There are six passenger airports controlled by Finnavia airlines<sup>2</sup> in Lapland.

There is a direct connection between tourism and herding. Herding is a distinctive livelihood tradition of local indigenous Sami people. Their developed crafts and reindeer products are a valuable asset for tourism businesses. Through tourism activities, local knowledge can be mobilized, sustained and reconceptualized as cultural heritage (Müller & Huuva, 2009). Therefore, the decrease in herding culture can negatively affect tourism and the other way around. On the one hand, slower tourism flows generate lower profits for herders from the goods they create and sell. Resorts occupy space, need functional connectivity and fragment the landscape. Furthermore, the foreseen increase in tourists also means an increase in flight numbers and noise, leading to herds to avoiding the airport territory. Growing tourism boost the region's urbanisation as demand for new services grows depleting region's branded pristine image (Pashkevich, 2014).

Problematic situations often occur between tourism and mining activities. If mining comes first, then new tourism entrepreneurs can adapt their business plans to the fact that the mine is already there, but it does not work the other way around. The entire business is in danger if the image of a tourism destination is tainted because of its proximity to a mine. One reason for the lack of debate about the possible impact of mining on tourism is the relatively significant distance between mines and tourist resorts in Lapland. Only the Hannukainen iron mine is situated within a short distance (10 km) of a famous tourist resort, Ylläs (Similä & Jokinen, 2018).

Shipping and infrastructure patterns also contribute to the tourism pattern since tourists are also carried by ships and trains.

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1 Growth of international tourists can also indicate need for more flights or better infrastructure to reach tourist destinations (<https://www.lapland.fi/business/facts-figures/infographic-10-facts-about-tourism-in-lapland-2019/>).

2 International and domestic passenger flight statistics is used in following chapter as an input dataset <https://www.finnavia.fi/en/about-finnavia/about-air-traffic/traffic-statistics/traffic-statistics-year>



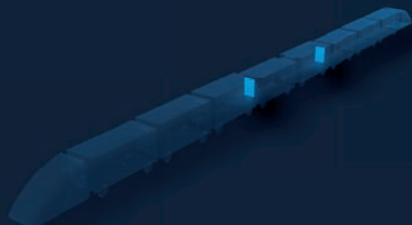
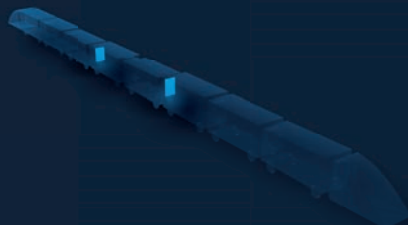
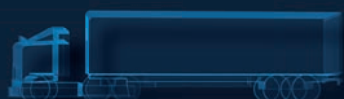
# Chapter 5

## *Reflections*

*The introduced patterns have distinctive directional and temporal characteristics. They can be parametrized and implemented in a computational simulation model. It is already noticeable that the descriptions of these patterns overlap, showing that they are tightly interconnected.*

*Only five spatial patterns were described in this chapter. However, the model is scalable and other existing or speculative narratives could be described through patterns, e.g. national security or energy.*

*Finally, while some patterns represent realistic phenomena that can be found and checked, others are speculative. Therefore, patterns are suitable to test speculative large-scale urban ideas.*





## PART II

# Application

*PART II is the creative and speculative thesis' section. It proposes a strategy on how the knowledge from the research done earlier and computational design methodologies can form an integrated whole in order to support large-scale urban planning and design processes.*

*This section introduces the process of creating a planning decision support tool comprised of a simulation model, a tangible user interface and incorporation of dynamic patterns. It describes how these parts were combined on a conceptual, as well as, technical level.*

*In the following chapters, the author discusses ways how planners, experts and stakeholders can approach the complex challenges of future urban development in the Finnish Lapland.*

*Finally, it presents the most important discoveries and outcomes and proposes further steps for project development.*

# Chapter 6

## *Intro*

*This chapter presents the main methods used to apply the background research done in PART I for the development of a decision support tool for urban planning and design tasks.*

*The chapter covers the relevance of simulation tools in urban planning and design processes, with a critical reflection on its benefits and shortcomings.*

*Furthermore, it briefly describes the main characteristics of the GAMA simulation platform, agent-based and pattern-oriented modelling, as these aspects could be a subject of research itself.*

*The chapter also describes the CityScope tangible user interface that is used to facilitate the simulation model. Its goal is to allow community members, local authorities and design professionals to explore alternatives and receive real-time feedback to their ideas.*

## 6. Research application

### 6.1. Merging research and tangible participatory tools

There is a growing need for creative solutions on how to understand and use complex datasets. It is necessary in order to employ complex Arctic patterns introduced in the previous chapters and empower stakeholders for better-informed planning decisions. This often requires combining multiple elements, both software and hardware. Furthermore, design solutions for complex environments like the Finnish Lapland are challenging to test and evaluate, since it undergoes rapid transformations which are hard to predict. Fast tests and receiving immediate feedback is, therefore, necessary when exercising regional scale urban planning ideas.

In PART II, the author presents a multi-level interactive and tangible interface setup consisting of technical and conceptual elements that, as a whole, visualize time and directionality patterns of distinctive agents in the Finnish Lapland. The presented framework is embedded in the MIT CityScope setup used for civic engagement, urban development, and decision making (Grignard et al., 2018). The agent-based model implemented with GAMA simulation platform (Taillandier et al., 2019), provides a dynamic simulation in which users can instantly identify a set of main elements: 1) clear representation of the location area defined by geographic attributes like country boundaries, seas, lakes and cities 2) different types of agents, like trains, herds or tourists 3) the agents relational conflicts in terms of time and direction (see Chapter 7).

### 6.2. The relevance of urban simulation tools

Current urban planning and urban design strategies aim to merge temporal and spatial data to enhance the well-being of urban populations (Crooks et al., 2008). To understand this temporal and spatial data better, stakeholders need tools that address the internal correlations between multiple dimensions of the regions, cities or specific places. For instance, no decision-support tool currently addresses and quantifies the agent's directionality impact on Arctic urban development or the relations of time patterns among agents. Therefore, there is an increased demand for other forms of decision support tools for planning and design tasks.

As mentioned in Chapter 4, the time aspect is critical in order to more explicitly represent the occurring changes. While mapping is a well-established planning method, it does not convey the dynamic aspect of the built environment in real-time. Meanwhile, digital simulation is more capable of that. By merely presenting the interaction of critical variables over time, simulations allow stakeholders to explore changing processes through dialogue in real-time. Each simulation is based on a designed model which is usually evaluated by the extent of insight it gives, whether it stimulates discussion, inspires innovation, and helps to resolve societal problems (Arctic Council, 2016).



A range of urban simulation tools is available to this date. For example, UrbanSim initially developed by Paul Waddell is a model system that addresses land use, transportation, environmental qualities, real estate markets and effects of growth on the built environment (Waddell, 2002). Another example, SimTable<sup>1</sup>, combines digital sand tables, agent-based models and GIS, has been used in a number of cases: emergency management, active fire areas, urban security and other situations. The Relational Urbanism Lab<sup>2</sup> with its designed interface called Relational Urbanism Models (RUM) presents a workflow that constitutes a new approach to planning, decision-making and development strategies by non-experts. It is a dynamic tool with real-time updates in a 3d model and output data.

The general purpose of simulation tools is to help users understand the impact of decisions in a quantitative fashion. Unfortunately, such simulation tools are often hard to learn or consume a vast amount of computational resources to run each iteration, which can take up to hours or even days. Furthermore, many simulation tools only focus on a single aspect of the performance, whereas a city is a complex system (Zhang, 2017). Therefore, there exists an increased focus on easy-to-implement simulation modelling platforms that are not only able to create simple but also spatially explicit, complex models with different levels of representation. The CityScope setup, developed by MIT Media Lab researchers, could be named as an example of such a simulation platform: tangible, iterative and currently used in multiple real situations. It is not only used by researchers but also municipality authorities, universities and tourism sector representatives (Noyman et al., 2017; Alonso et al., 2018; Grignard et al., 2018).

### 6.3. Agent-based model as a simulation tool

*“... models allow us to build a comprehensive understanding of the mechanisms and behaviours that shape complex geographical phenomena.”*

—Crooks et al., (2018)

Models are often seen as an abstraction of the world with a focus on a specific question. Based on their purpose, they can either explain, predict or explore through visualising patterns that are otherwise invisible. The model used in this thesis uncovers time and direction patterns of selected narratives in the Finnish Lapland. Modelling as a decision support tool for a broad range of stakeholders here represents an opportunity to combine quantitative and qualitative theories and to change between observations and hypotheses within the same framework (Crooks et al., 2018).

The agent-based approach (ABM) is a style of thinking that defines the system not in aggregates formed from individual populations but concerning individual entities at many different levels of spatial aggregation

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<sup>1</sup> <http://www.simtable.com/applications/>

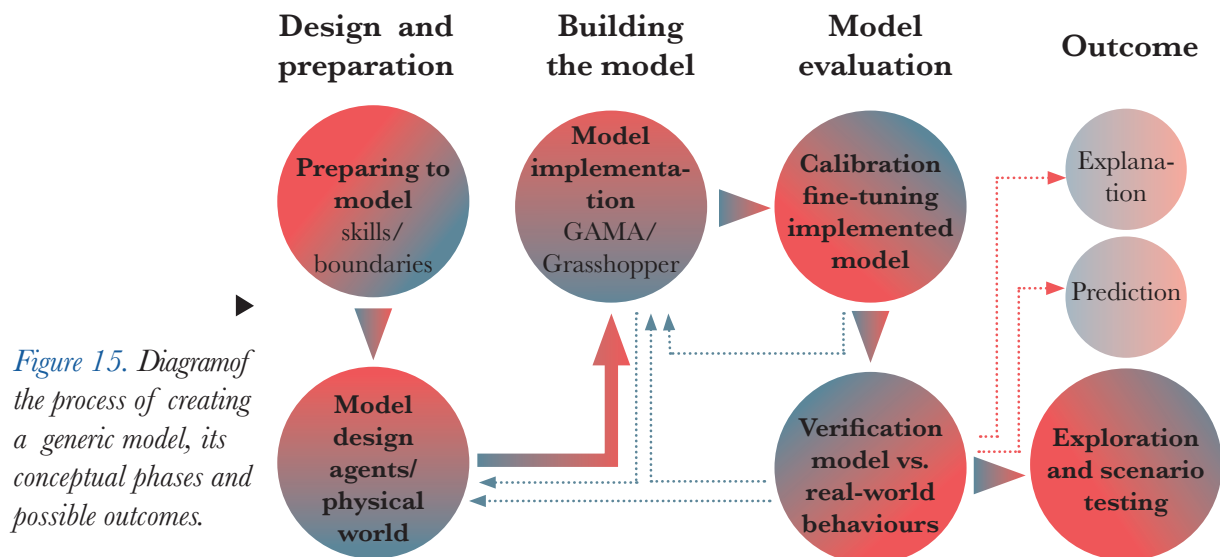
<sup>2</sup> Architects Eduardo Rico and Enriqueta Llabres have created both tools and methodology for relational urban design in partnership with the engineering firm Arup (<http://relationalurbanism.com/>).

(Crooks et al., 2018). Those entities, called agents, are considered to be dynamic and autonomous. They have attributes, relationships based on which they operate in an environment interacting and they are organising themselves (Cantrell & Mekies, 2018). They might represent a multitude of phenomena ranging from the particle and cell to individuals or groups. ABM are characterised by their complexity and their dynamic, heterogeneous, multi-scale character (Drogoul, 1993).

The type of model discussed in this thesis (see Chapter 7) and used for the application is based on the pattern-oriented, agent-based approach. Pattern-oriented modelling (POM) is an approach to bottom-up analysis with emphasis on patterns, where agent's behaviour is translated into reoccurring events forming patterns (Grimm et al., 2005). This type of modelling has a low level of uncertainty, lower sensitivity to parameters and is structurally realistic.

The model environment allows observing agent behaviour over time. This feature is particularly important in the case of the Finnish Lapland. The region goes through fast and slow changes that can only be understood in time perspective, e.g. impact of lower levels of annual accumulated ice for increasing Arctic shipping activity. Unfortunately, commonly used static images and plans do not show the reoccurring correlations that present the region as a system over time.

The process of developing a model consists of multiple stages (see Figure 15). Some of them are more crucial than others. In the first stage, it is important to prepare for the modelling: to have control of the tools, know its peculiarities and to decide model conceptual boundaries. In the second stage, the modeller designs the model structure and linkages between the physical environment, agent species, its behaviour, simulation time step and global rules. During the third stage, the modeller decides what forms of representation to use, chooses suitable datasets and strategies to implement it practically. Then follows the calibration, verification and validation stage when the model is fine-tuned and checked. The last stage is model output, where a working model either predicts, explains or explores.



*Figure 15. Diagram of the process of creating a generic model, its conceptual phases and possible outcomes.*

Exercising such understanding of a system helps to be prepared for different scenarios and focus on potential impacts of different behaviours. Its utility depends on whether it responds to a realistic pattern of behaviour. Particularly for planners and designers, modelling skills help to process and develop a holistic approach, in order not to represent the world as it is but to exercise new ways of seeing it, focusing on underlying patterns.

#### **6.4. CityScope - Tangible User Interface**

There exist coordination and collaboration challenges associated with traditional planning methodologies: 1) the planning process includes some stakeholders too late in the decision-process 2) the planning process takes long periods, not providing a testbed for immediately examining different ideas. While a workshop culture is emerging as a tool for communication between different stakeholders, it often lacks the inclusion of empirical data.

In this thesis, the CityScope tangible user interface setup is used to address the aforementioned challenges (see Chapter 9). It is an ongoing research theme at the MIT Media Lab CityScience group. Projects, where it is used, are mostly demos – generic and scalable tools or deployments, as useful tools in small- and large-scale planning processes (Hadhrawi & Larson, 2016).

CityScope facilitates explorations and insight building through a participatory process, which allows community members, local authorities and design professionals to understand challenges, explore alternatives and receive real-time feedback in response to proposals or interventions.

This setup aims to visualise the complex urban data, simulate the impact of real-time interventions, support decision-making in a dynamic, iterative and evidence-based process using a tangible interface and to open up new opportunities to innovatively address the demand of proper collaborations and public engagement (Alonso et al., 2018).

CityScope usually consists of three layers: computational, tangible and interactive. The computational layer includes the abstract elements of the platform: data and simulation models to perform data-analysis processes and visualisations. The tangible layer includes physical elements through which stakeholders interact with the simulation. The interactive layer allows stakeholders to interact in real-time through a set of elements like cameras or sensors. Therefore, a typical CityScope setup consists of running a real-time simulation model, projected on a table that uses different interaction modes like cameras or LEGO® modules, scanning and capturing the real-time physical change of the scene and updating the model accordingly (Hadhrawi & Larson, 2016).

#### **6.5. GAMA Platform: spatially explicit agent-based simulations**

The engine used to simulate agent behaviour in the model is the GAMA modelling and simulation platform, developed since 2007 as an open-

source project<sup>1</sup>. It aims at providing modellers with tools to develop and experiment highly complex models through a well-thought-through integration of agent-based programming, and GIS data, flexible and high-level visualisation tools and multi-level representation and co-modelling (Taillandier et al., 2019). It is currently applied in multiple projects in planning (Nguyen et al., 2012), water management (Gaudou et al., 2013), climate change adaptation (Bhamidipati, 2015) or disaster mitigation (Macatulad & Blanco, 2014).

GAMA is a software application mainly built on the Eclipse provided RCP architecture<sup>2</sup>. Within this single application software, users can perform most of the activities related to modelling and simulation. Agents can be instantiated from any dataset, including GIS data. The platform can handle several thousands of agents in real-time rendering in 2D/3D displays (Taillandier et al., 2019).

This simulation platform provides a complete agent-oriented modelling language GAML (Gama Modeling Language). Modellers define species of agents, i.e. archetypes of agents, including characteristics, behaviours and aspects. The behaviours of agents are defined through actions and reflexes and the agents are displayed through aspects. An action is something that the agents can do, or other agents can evoke it. A reflex is a behaviour, i.e. something that the agents of the population are going to do if some conditions are fulfilled.

The essential feature of why GAMA platform was chosen for this thesis is its ability of multi-level modelling and support of large-scale models. Multi-level agent-based modelling (ML-ABM) requires representing agents at different levels of representation concerning time, space and behaviour in the same model (Grignard et al., 2013). Agents in Finnish Lapland spans various scales. Therefore, the model needs to take into account entities at different spatial or organisational scales. This need justifies the choice of multi-level, agent-based modelling.

This problem of multi-level representation and articulation between agents at different levels is considered as one of the hardest issues to be tackled in the domain of complex systems modelling.

## 6.6. Common challenges in simulation modelling

Simulation modelling can be challenging due to representation difficulties of agent-based models (Grignard & Drogoul, 2017). The visual presentation of information involves a multitude of theoretical principles, both analytical and graphical. The designer should critically evaluate the presented material in order to prevent misleading communication. Hence, special attention in the following chapters is given to the choice of data, as well as, the presentation method. For example, in the final decision support tool, outputs are divided between CityScope table and additional displays using different forms of representation.

The chosen level of abstraction or too high information reduction

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1 <http://gama-platform.org>

2 [https://wiki.eclipse.org/Eclipse4/RCP/Architectural\\_Overview](https://wiki.eclipse.org/Eclipse4/RCP/Architectural_Overview)

might lead to an inaccurate system representation (Meadows, 2008). Also, determining, studying, and drawing conclusions from anticipated impacts is a complicated endeavour, since they can vary significantly in different places and times (Stephen, 2018).

Special attention was given to the choice of data in terms of what to present and to which extent. There must be a fair representation and clear illustration of the behaviour and dynamics while excluding elements that might distort the results or disorient the observer. Therefore, a model presented in the following chapter is a rich abstraction of Finnish Lapland system and the Arctic Ocean Railway, but not a representation of all its parts.

Finally, there exist multiple modelling styles, e.g. “consolidative” and “exploratory” models. The difference between them lays in their purpose. The consolidative style tends to focus on the construction of models that might ultimately provide accurate or focused predictions. Exploratory models will never do so, but they are used to define salient characteristics, to “inform” the debate over particular problems and to engender learning among stakeholders (Bankes, 1993; Batty, 2013). Later one is chosen for this thesis.



# Chapter 6

## *Reflections*

*The chapter introduced the main concepts important to create a simulation model of a complex system.*

*Each model is an abstraction of the existing world. Therefore, it might be a challenge to operate it, select the relevant data and understand the abstraction level. However, a simulation model can visualise the dynamic changes in the built environment in real-time in a quantitative fashion. This aspect is essential when dealing with temporal spatial changes.*

*Additionally, agent-based, pattern-oriented models have a low level of uncertainty, lower sensitivity to parameters and are structurally realistic. Therefore, they are suitable to apply in real-world situations.*

*Finally, the tangible user interface with immediate feedback systems allow users and stakeholders to collaborate more effectively and to perform rapid experimentation.*

# Chapter 7

## *Intro*

*The following chapter introduces the design process of the created simulation model and its outputs in the case of the Finnish Lapland along the potential Arctic Ocean Railway.*

*The chapter introduces the simulation model's structure and describes its components: agents with unique behaviour, the physical environment and the interaction between it.*

*Different model outputs, like collision maps, collision counter, direction vector map and agent's effort to move displays are also presented and explained.*

*The model created in this thesis explores possible future scenarios and asks "what if" questions within the context of the future urban development of the Finnish Lapland. Its utility depends not on whether its driving scenarios are precise, but on whether it responds with realistic agent behaviour.*

## 7. Model Design

### 7.1. Model goal

Only five patterns (see Chapter 5) representing selected spatial narratives are introduced in this work and represented through agents in the model (see Figure 16). Its goal is not to include everything, but to visualise how information about fewer or more patterns could be used to improve the decision-making process in planning and design tasks. However, there exist many more narratives with unique varying patterns that could be incorporated, e.g. national security or energy. The potential of this method is the ability to compose a model through adding or removing different spatial narratives and observing results created from analysing, two, four, ten or twenty patterns in the same model.

The simulation model structure consists of 1) inputs 2) interaction simulation between agents in GAMA platform and 3) outputs. Inputs are agent attributes like heading, content, schedule, source and location that as a whole forms agent's behaviour. These attributes are translated from the selected spatial narratives. GIS layers visualising a specific physical environment are also included as an input. The running model simulates the interaction between agents and virtual environment, generating direction and time patterns (see Figure 17). As an output, it produces collision maps and direction vector map with additional supporting displays. The user can test new urban scenarios by changing the parameters of agent behaviour directly inside the GAMA interface (see Figure 18).

While a few thousand agents can be simulated smoothly in real-time, the complexity and regional scale of this model meant that the number of included agents had to be limited to the most relevant. Knowing how rapidly computing power grows with technical developments, incorporating extensive datasets will become a normal process. Furthermore, more detailed insights from experts on occurring patterns will improve the precision of this model. Experts could help to distinguish which information is more relevant to define patterns of selected narratives which span diverse fields and bodies of knowledge.

The importance of investigating introduced patterns lays in the impact they have on on-going spatial transformations in Finnish Lapland. Exploring these patterns, e.g. consequences of increased traffic in the Arctic Ocean and along the Arctic Ocean Railway on tourism or herding, can provide insight about the phenomena itself and support in making more informed decisions.

### 7.2. Model validation

Since the simulation model input consists of factual and speculative data, it is challenging to validate the results. For instance, the implemented flight statistics' resemblance to the real-world situation is easy to test. At the same time, train schedules and future shipping patterns in the Arctic Ocean can

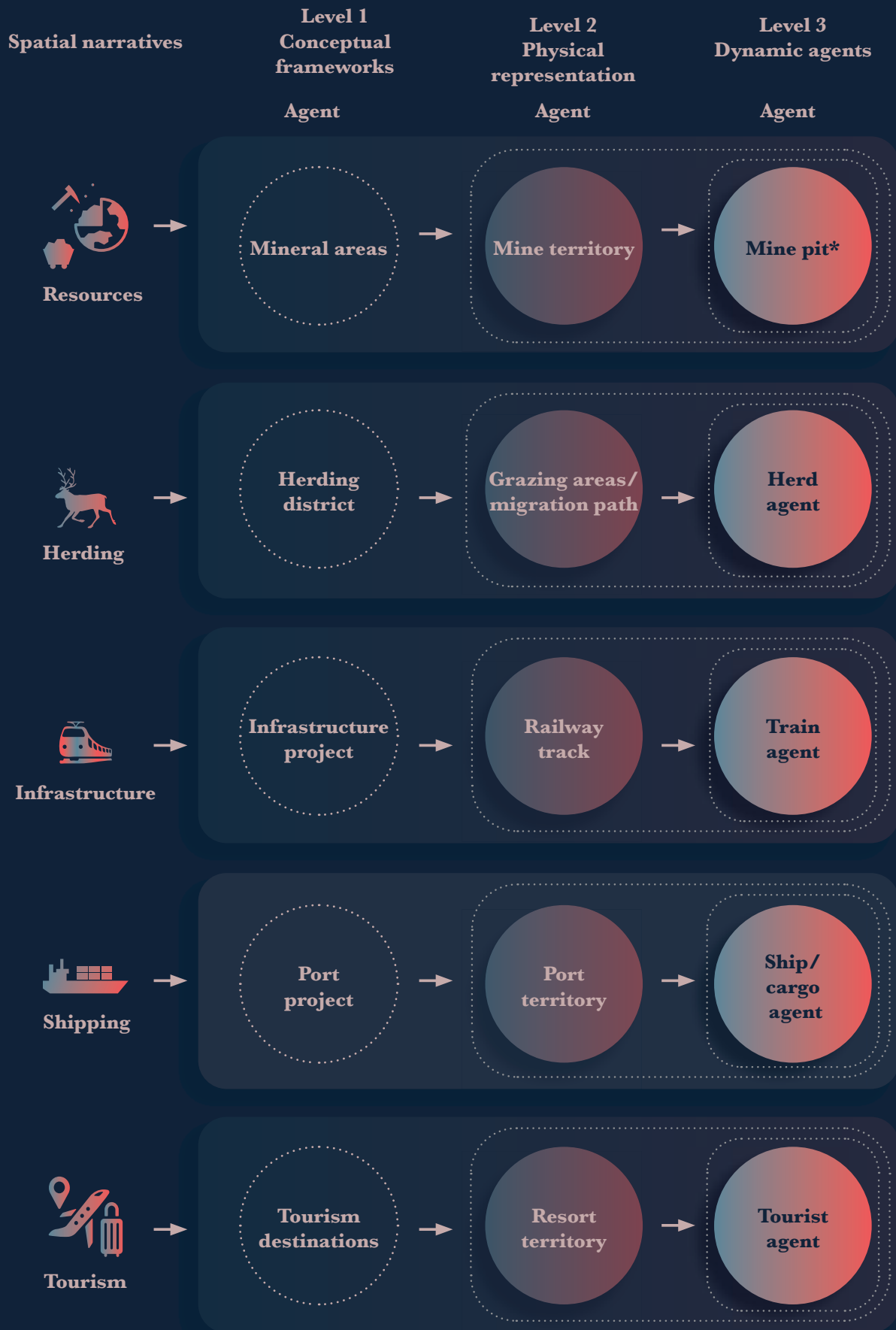


Figure 16. The diagram shows selected spatial narratives for the model and its representations on multiple levels. \*Resource level 3 agent would likely be resource flows from the mine, however, it is difficult to access such information.

only be speculated and based on forecasts.

### **7.3. Datasets used in the simulation model**

A range of datasets was used to create a representative, physical model environment and realistic agent behaviours. While the implementation of the physical world was straightforward through the use of GIS shapefiles, the implementation of agent behaviour required an in-depth understanding of the system these agents create or belong to, patterns noticeable in their behaviour and the relation to each other (see Chapter 5). Such a complex system required to factor in several sources, e.g. the Arctic Monitoring & Assessment Programme (AMAP) reports, scientific papers published by international or national organisations, feasibility studies and reports from different agencies discussed in the earlier chapters (see Chapter 2). In the case of the Arctic Ocean railway, the Finnish Transport Agency wrote the feasibility study.

Agent species in the model of the Finnish Lapland, either exist in the real world, like herds and mines or are speculative like trains or cargo ships. However, as discussed earlier, they all have common attributes like direction or a schedule/cycle. Through implementing these attributes, a unique system of the Finnish Lapland is being simulated.

### **7.4. Physical environment**

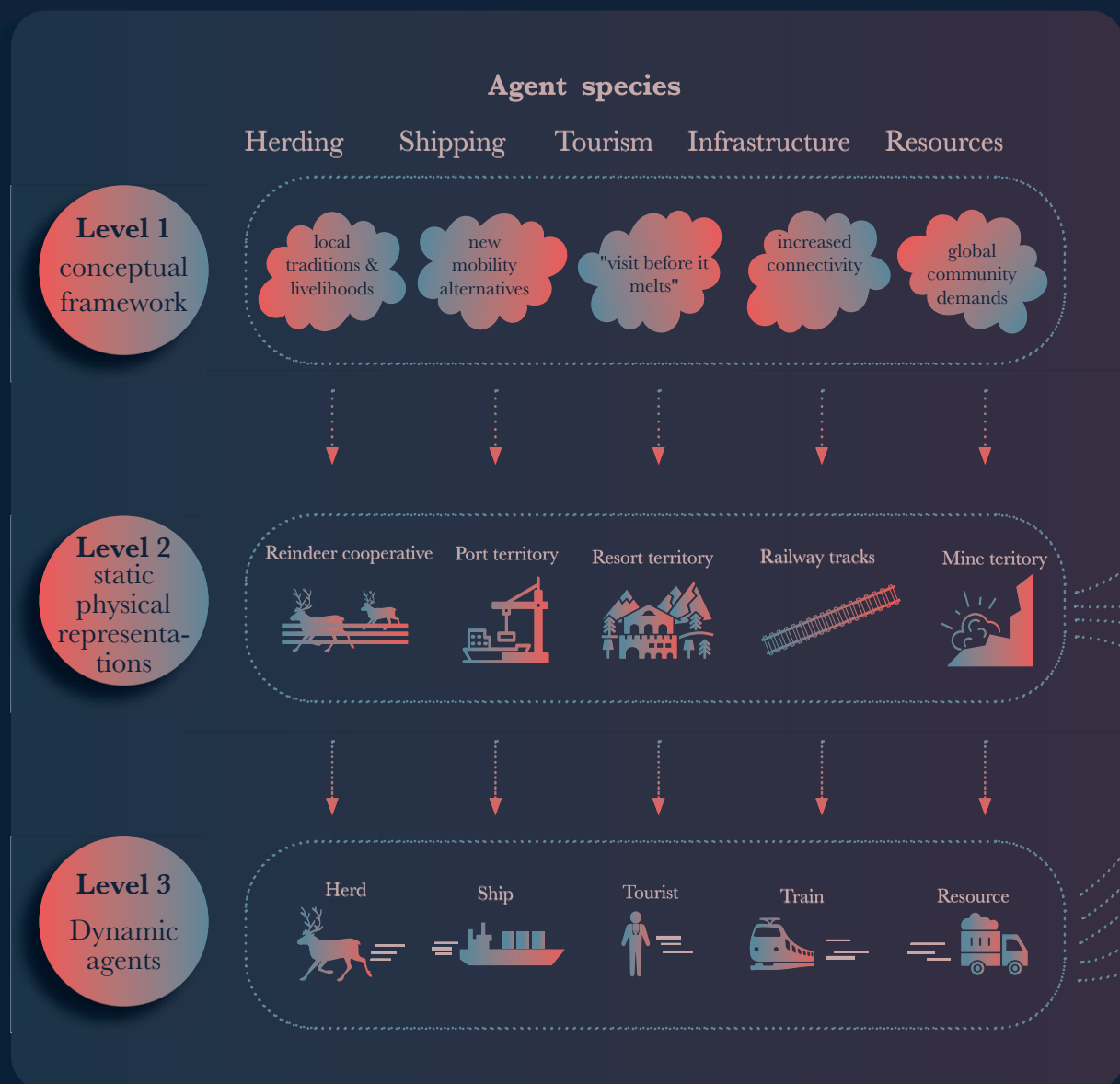
The physical environment in the model is represented through the interpretation of GIS layers given as an input to the GAMA simulation platform to create a geo-specific situation. These layers work as a testbed for different agent interactions and also affect individual agent behaviour.

The physical model boundary is limited to the Finnish Lapland territory bordering Sweden, Norway and Russia. Relevant parts of the mentioned countries, as well as the Arctic Ocean and Baltic sea, are also displayed. The model incorporates country borders, herding district administrative divisions, reindeer grazing areas and migration paths, water areas and pathways, the main road network, railways, wilderness areas or national parks of great importance, locations of urban settlements, airports, natural resource reserves, mines, ports and resorts. The model also integrates topographic information, e.g. terrain elevation and slope, because terrain conditions are crucial for specific agents' behaviour and interactions.

### **7.5. The overview of agent behaviour**

As mentioned earlier, five dynamic agent species were used in this model: ships, trains, mines, tourists and herds. They represent the distinctive patterns in five selected spatial narratives (see Chapter 5). While all agents have a set of attributes, the primary attention is given to time patterns — schedule or cycle according to which agents show different behaviours — and to the direction they have at any given moment. These two attributes





### Built environment

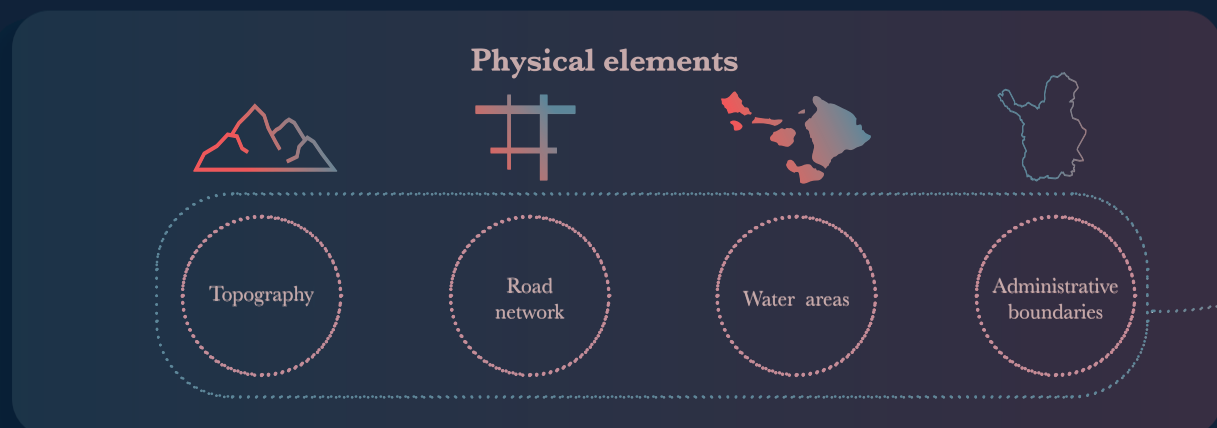


Figure 17. Diagram showing the model structure: 1) agent species 2) input: agent attributes, built environment datasets, rules and conditions 3) inner model processes and 4) outputs: collision and direction vector maps.

Simulation

Inputs

Outputs



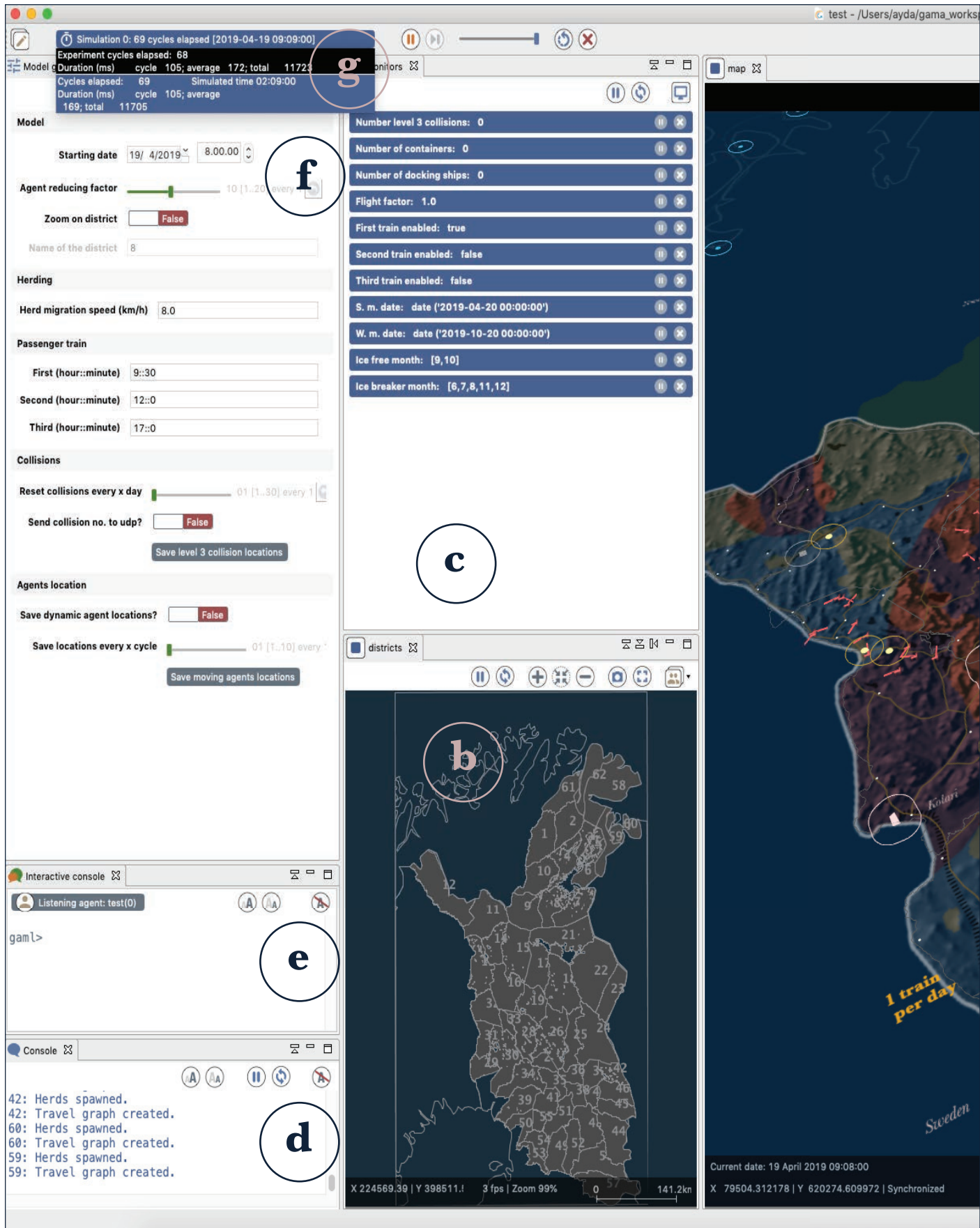
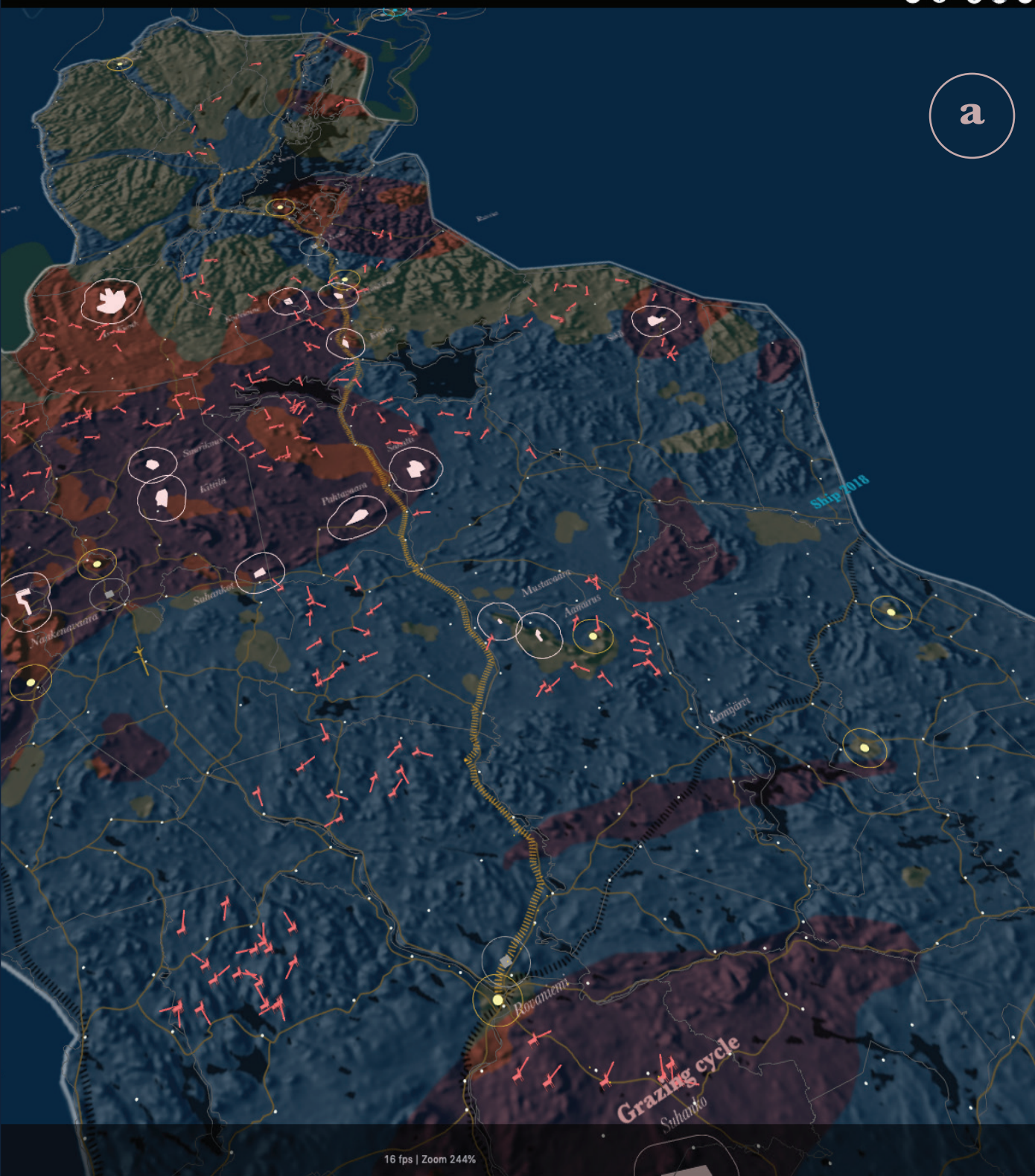


Figure 18. The image shows GAMA interface with the 3d display window (a), the 2d display window (b), model parameter interface (c), interactive console (d), console displaying carried actions (e), tracked variables(f), internal simulation clock(g).





a



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have a tight connection since changing time pattern affects the agents' direction and vice versa. The extent to which each agent is implemented in the model is presented below.

*Ship agent*

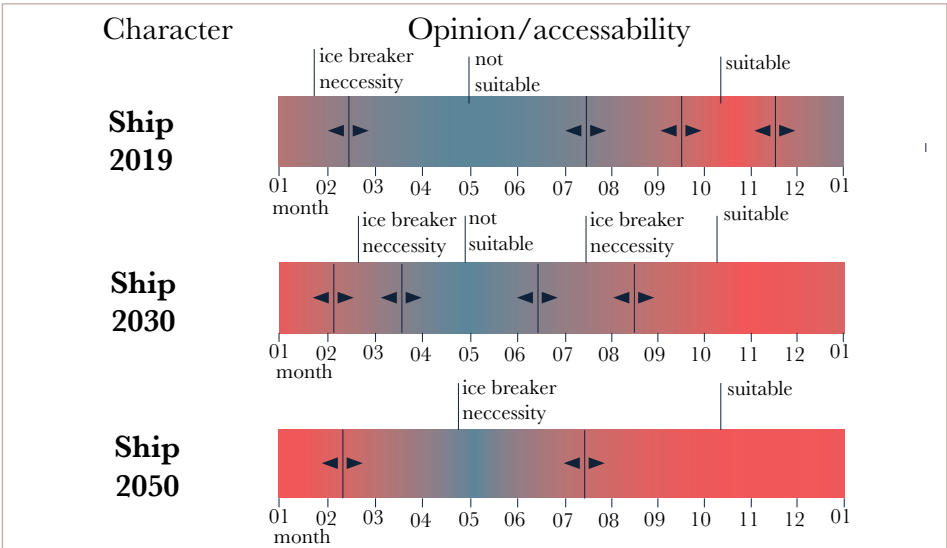
The ship agent generally has four attributes: source (ports), schedule, content (passengers or containers) and direction. There are two types of ship agents: passenger and cargo ships. Two abstract points in the model represent ports from where ships can be spawned.

**Source.** In the case of a passenger ship, the sources are the Bergen (theoretical point) and Kirkenes ports. For cargo ships, the source is a theoretical point in the Arctic Ocean that represents the origin of all arriving ships to Kirkenes port.

**Schedule.** The passenger ship agent travels according to a schedule: daily arrival in Kirkenes port at 09:00 and departure from Kirkenes southbound to Bergen at 12:30, stopping at other main ports for 3.5 hours and releasing tourist agents.

Based on research done earlier, the Arctic cargo shipping schedule strongly depends on ice accumulation over the year, which results in suitable or not suitable shipping conditions. Altering the ship agents' choice when times are suitable for travelling through a bottom-up approach can represent global shipping patterns.

Cargo ships spawn every day, but based on the current data and the related ice coverage, they evaluate if it is suitable to start the trip. Depending on its set preferences, the agent starts the trip or is erased. These preferences represent different global shipping scenarios. A ship of 2018 could only travel within a 7.4 months window per year, where only a few months are ice-free and do not require icebreaker support. It makes this period more suitable for the trip and increases the probability of an agent to choose to start the trip. A ship with 2030 preferences assumes that the Arctic Ocean is ice-free most of the year. Therefore, the probability of making the trip is high throughout the year. Similar preferences could be assigned to a shipping agent that represents 2030, 2040 or 2050 global



◀ *Figure 19. Diagram showing the possible cargo ship agent types based on different Arctic ice conditions. The types can be changed through interaction with the CityScope Lapland table.*



shipping conditions.

**Direction.** The passenger type ship agents have the inward and outward direction for Kirkenes port. Cargo ship agents have only inward direction.

**Content.** The passenger ship agent is not actively interacting with other agents, but it delivers other groups of agents into the region — its schedule may affect the reoccurrence of tourist agents. It has 300 – 600 passengers that leave and enter the ship in the stops, depending on the ships' capacity. One cargo ship on average can transport 4800 TEU containers, and depending on the port, takes 2-3 minutes to unload one container. The containers accumulate in the port where it is then picked by the spawn train agent.

The interactiveness with this agent through the Cityscope Lapland table is implemented by allowing to choose the agent's preferences suitable for shipping months (see Figure 19).

The shipping agent is represented with a ship icon that has a different colour for the passenger and cargo ship agent with an arrow vector showing the agent's direction. Ports are displayed as dots with an offset outline of the overall impact area. Passengers released from the ship are displayed as yellow dots.

### *Train Agent*

The train agent has five attributes: source (start and end station), schedule (frequency), direction (target), stops (stations at which the train stops) and content (passengers or cargo). Its trajectory is constrained to a graph that represents the Arctic Ocean Railway.

**Source.** The train agent can move on a railway graph connecting Kirkenes and Rovaniemi. These two cities are the only sources where trains can be spawn.

**Schedule.** In the feasibility report from the Finnish Transport Agency, it is estimated that 300,000 passengers with one daily train in both directions or 600,000 passengers with two daily trains in both directions would make the project feasible (Finnish Transport Agency, 2018). One, two or three daily train frequencies are implemented in the model with the ability to adjust departure times. In case of one daily train, the agent is spawned at Rovaniemi and leaves at 9:30 am. daily towards Kirkenes travelling with 80 km/h. It departs again from Kirkenes at 5.00 pm.

The cargo train frequency is highly interconnected with the ship agent activity. In the model, whenever a ship arrives at the Kirkenes port and unloads 125 containers, a train is spawned in Rovaniemi for a north-bound trip to collect containers at Kirkenes port and then to return to Rovaniemi to unload the collected cargo. It moves with 120km/h and does not have in-between stops. Depending on the number of unloaded containers at the port, the number of daily trains can reach up to 10.

**Stops.** Stations between endpoints are calculated based on population size in each urban settlement and distance to another urban settlement. In this way, the algorithm assigns stations to sparsely populated

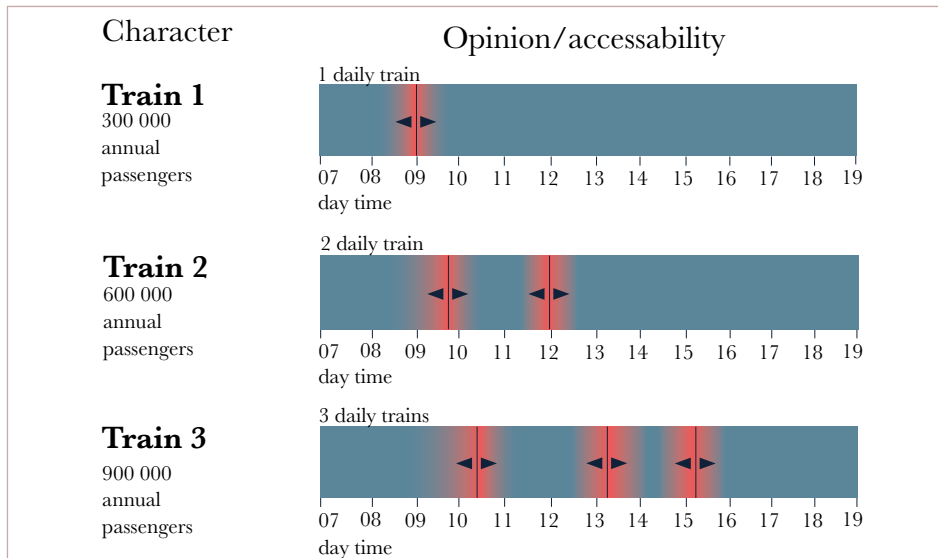


Figure 20. Diagram showing the interaction possibilities with the Lapland CityScope table for the passenger train agent. The user can change the frequency of trains per day.

locations, as well as, densely populated locations with reasonable intervals. At each in-between station, the train agent stops for 5 minutes and releases passenger agents. The same process is implemented in the opposite direction at 5.00 pm - from Kirkenes towards Rovaniemi. In the case of a different route, a new set of cities would be automatically chosen for stops.

**Direction.** The train's direction is defined by its destination — a vector on the railway graph towards Kirkenes or Rovaniemi.

**Content.** In each direction, the passenger train has a number of passengers which at any given point can not exceed the train's capacity. At the destination point and in-between stations, a number of passengers are released, which move on the road graph to an urban settlement or a resort in close vicinity to the station. The number of passengers slightly evolves, according to seasonality, day time, and direction.

Cargo train's content, as mentioned before, are containers loaded in Kirkenes port. A maximum of 125 containers can be loaded to a standard European freight train, which results in a train length of approximately 750 m.

Interactiveness with the passenger train agent is created by allowing different test scenarios with one, two or three daily trains driving from Rovaniemi to Kirkenes and back (see Figure 20). The same is not applied to freight trains since its spawn rate is dependent on ship activity.

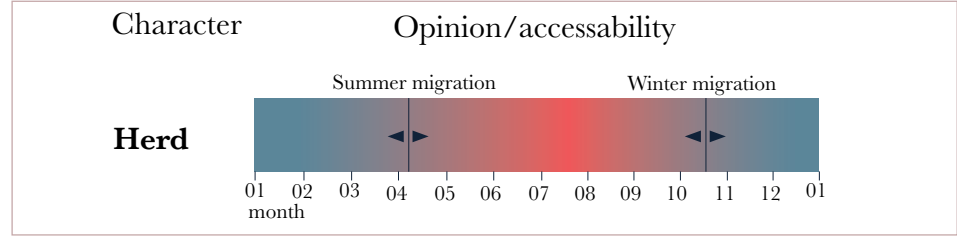
Train agents in the model are represented by a train icon with different colours for cargo and passenger trains and direction vectors. Passenger agents are represented with a yellow dot. The railway is displayed as a dashed yellow line.

### Herd Agent

The herd agent has three main attributes: source (grazing area), schedule (grazing and migration cycle) and direction (heading).

**Source.** Depending on the starting date of the simulation, herd agents are spawned in summer or winter grazing areas. The locations for winter and summer grazing areas are based on suitable land cover over the year.

Figure 21. Diagram showing the interaction possibilities of the Lapland CityScope table with the herd agents. The user can change the start of summer and winter migration.



**Schedule.** The herd agent's behaviour consists of four states implemented using a Finite State Machine (FSM). The FSM is a computation model mainly used to simulate sequential logic, in this case, the agent's behaviour (Aaronson, 2011). The four-movement states are: 1) wandering state in the winter grazing areas, 2) migration state along migration path towards the summer grazing areas, 3) wandering state in the summer grazing areas and 4) migration state along migration path towards the winter grazing areas. These movement states are constrained by the initial reindeer herding cooperative boundaries, topographic obstacles like slopes or water areas and infrastructure elements. On average, reindeers move 20m/h in the wandering state and 8 km/h in the migration state. The migration period usually lasts around two weeks. Every herd agent switches from wandering to migration state at a random date within this two week period. The migration path is created using the Rapidly-exploring random tree algorithm (Karaman & Frazzoli, 2011). Once the agent reaches the migration path's destination, wandering state is initiated.

**Direction.** The agent's heading depends on the movement state it is in. The times an agent changes from one state into another affects the agent's direction. In the wandering state agent's heading randomly changes within each step. During the migration state, agent's heading is a vector along the migration path towards the next grazing area. Migration states are initiated at different times strongly depending on climatic and other factors. For example, the migration from summer to winter grazing areas starts when a specific average temperature is reached and terrain conditions are suitable for reindeers to walk.

The interactivenss with herd agents is implemented through the possibility of changing the dates when the migration should start, representing different scenarios of climatic and other conditions (see Figure 21).

Herds are represented with a reindeer icon with a different colour depending on the state and a vector representing the heading.

### Mine Agent

The mine agent has two main attributes: schedule (the mine's life cycle) and direction (inward or outward). Mines are level 2 agents, like airports and railway tracks, but it does not spawn dynamic agents. Instead, it changes its impact area based on the life-cycle phase.

**Schedule.** The mine agent's behaviour depends on the phase it is in. The lifespan of a mine consists of four phases: prospecting-exploration, development, extraction and closure-reclamation.

First, a mine goes through the prospecting-exploration phase, which can last between two to eight years. This phase involves the sampling

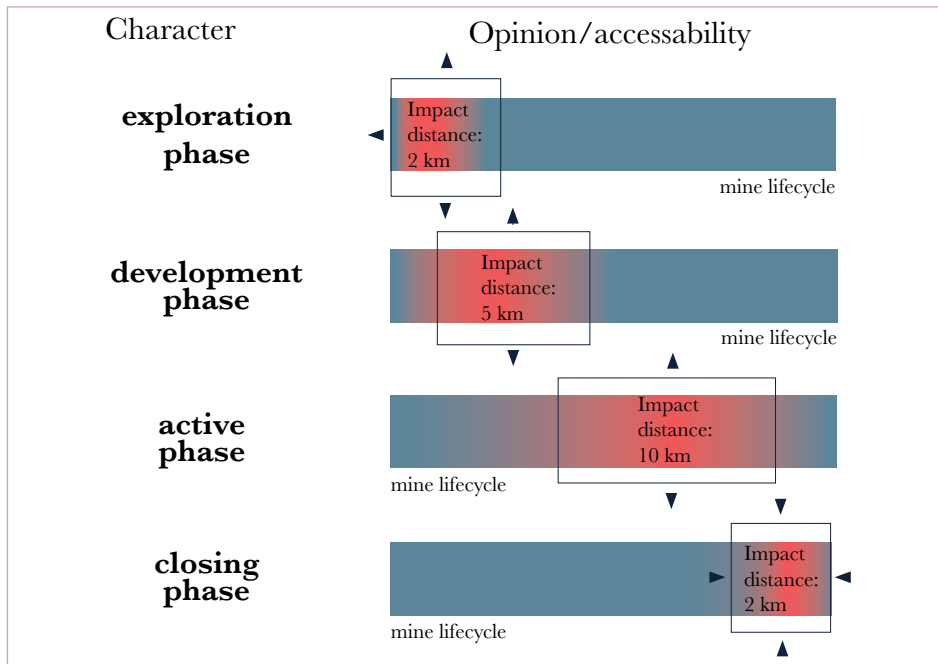


Figure 22. Diagram showing the interaction possibilities of the Lapland City-Scope table with the mine agent. The user can change the phase of the mine.

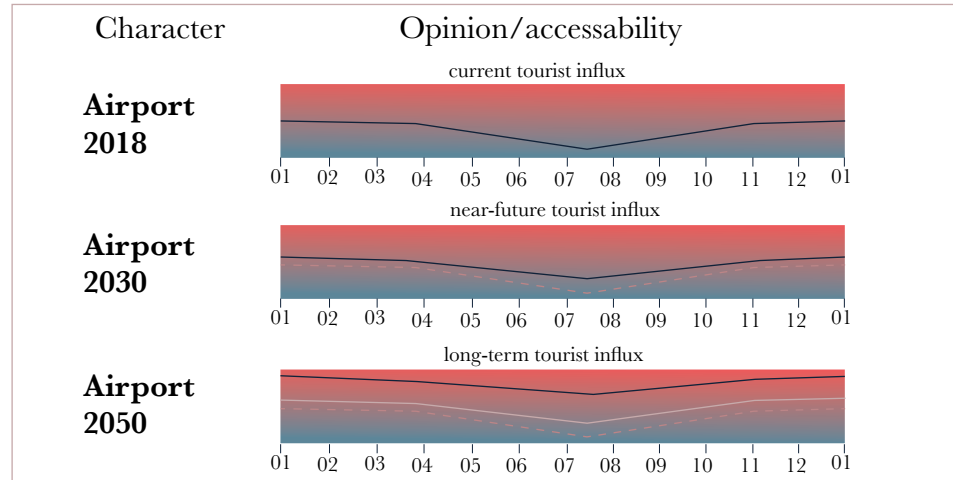
process and its impact on the physical area is not intensive. In the model, the impact is approximated by a 2 km radius around the potential mining location. When this period expires, the mine transfers to the development phase, which usually takes 4-12 years. During this phase, extensive planning is done together with building infrastructures like roads and the mine itself. A 5 km radius approximates the physical impact area. Next, the extraction phase is initiated. During this phase, the mineral is removed from the earth in large quantities. The extraction stage can take 5–30 years, but there are exceptions. In the model, the physical impact can go as far as 10 km around the mine. The planning for the closure and reclamation phase starts early in the mine's life cycle. The initiation of the closure phase results in shrinking the impact area of the mine. For the sake of model simplicity, a constant impact area of 2 km around the mine was chosen for this phase.

**Direction.** The agent's direction strongly correlates with the life cycle phase. During the prospecting-exploration and development phase, the direction of the mine agent is inward, resulting in population influx and increased activity in the area. The extraction phase has an outward direction since the removal of resources from the site intensifies and dominates. During the closure phase, the direction changes to inward, since its surroundings slowly reclaim the area.

The interaction with the mine agent is implemented by creating different impact distances around the mine pit, depending on the mine's phase. While the mine has a smaller physical impact (2 km) during the exploration phase, during the development and extraction phase, its physical impact is highest, spanning approximately 5–10 km around the mine (see Figure 22). During the closure phase, the impact disappears over time. In the model, this is represented by a fixed 2 km impact radius. Since all these phases are long-term processes, the impact of changing from one state to another and receiving immediate feedback is not prominent.

The mine is represented by a solid polygon and its impact by a line

Figure 23. Diagram showing the interaction possibilities with the CityScope Lapland table for the airport agent. Each scenario changes the amount of planes starting and landing



of the corresponding distance. The colour is different for each phase of the mine.

### Plane Agent

The plane agent has four attributes: source (airports), schedule (frequency), direction (target) and content (passenger). There are two types of plane agents — international and domestic.

**Source.** Kirkenes airport in Norway and seven other airports in Lapland work as a source that can spawn agents in the modelled environment.

**Schedule.** Datasets from Finavia statistics<sup>1</sup> became the base for implementing agent behaviour describing when and how many plane agents should be spawned and what amount of passengers they should accommodate. Flights per months are randomly distributed over the month's days and hours of the day, excluding the period from 0:00-6:00 am.

**Direction.** The flights' destination defines its direction. Depending on whether the plane is arriving or departing, its direction is either inward or outward.

**Content.** Whenever a plane lands at the airport, the plane agent disappears and passenger agents corresponding to the flights' capacity are released on the road network. They move to a random urban settlement or resort within a 50 km radius around the airport. Few hours before a plane departs a 'ripple' of the population moves to the airport through the road network. When a plane agent departs, it disappears after reaching 30 km distance from the departure airport.

To implement the interactiveness with the model, options for airport agents to spawn more or fewer plane agents can be chosen. They represent different scenarios of the overall increase in flights over the whole year (see Figure 23).

In the model, airports are displayed as dots with offset outline of the general impact area of 5km while the plane agent is represented with plane icon assigning different colours for international and domestic flights with direction vectors. The passenger agents are presented as yellow dots.

<sup>1</sup> <https://www.finavia.fi/en/about-finavia/about-air-traffic/traffic-statistics/traffic-statistics-year>



## 7.6. Model Outputs

Once the simulation model runs, it does not only simulate the agent's behaviour over time but also provides the users with different output layers: collision maps and direction vector maps. However, first, it is essential to explain what these outputs show and their potential to support the decision-making for various stakeholders, urban planners and designers.

### *Defining collisions*

Considering that there exist multiple narratives in the Arctic region with fragmented elements — that in some cases have contradicting goals — it might become difficult to evaluate at which level of this complex system conflicts emerge. The collision map can become a tool to distinguish moments when and where agents form colliding situations. For example, a new mine opens in a reindeer herding area, fragmenting and obstructing necessary land resources for reindeer herding. However, neither the trains are consistently going back and forth, nor are the reindeer herds at the same places throughout the year. Only at certain moments, these agents occupy the same location causing peaks of collisions. Furthermore, collisions will likely occur at the same locations, i.e. some spaces are more conflicting than others.

In the model, there exist three levels of collisions between different agent species. A supporting monitor displays its distribution among different agent pairs (see Figure 24). They are implemented in order to differentiate between conceptual, static and dynamic elements. In order to generate collisions, a list of conditions was set to evaluate whether agents' interaction is colliding (see Figure 25).

The dimension where spatial narratives of the agent species collide is defined as Level 1. Collision situations in this level occur when the compatibility between two different spatial narratives is hard or impossible to achieve. For instance, a railway project's spatial narrative might or might not collide with reindeer herding or tourism narratives. Since it is a conceptual non-physical level, collisions are counted only once.

Level 1 spatial narratives can be represented in specific locations through physical Level 2 agents. In the case of the railway project, Level 2 agents are the physical railway tracks and stations, in specific geographical locations, fragmenting the landscape or creating points of interaction. In the model, collision situations between Level 2 agents are counted based on the distances between two agents and whether their impact areas overlap. Since these are static agents, collisions are counted only once.

Level 3 agents are dynamic, move within or are spawned by Level 2 agents. For example, trains with their behaviour (individual schedule, speed and type) are Level 3 agents, causing temporary "ripples" in space. Collision situations in this level are counted either when two dynamic agents get too close to each other or when a dynamic agent gets too close or within the impact area of a Level 2 agent. Since level 3 agents are dynamic, collisions are counted when they occur (dynamic with dynamic) or

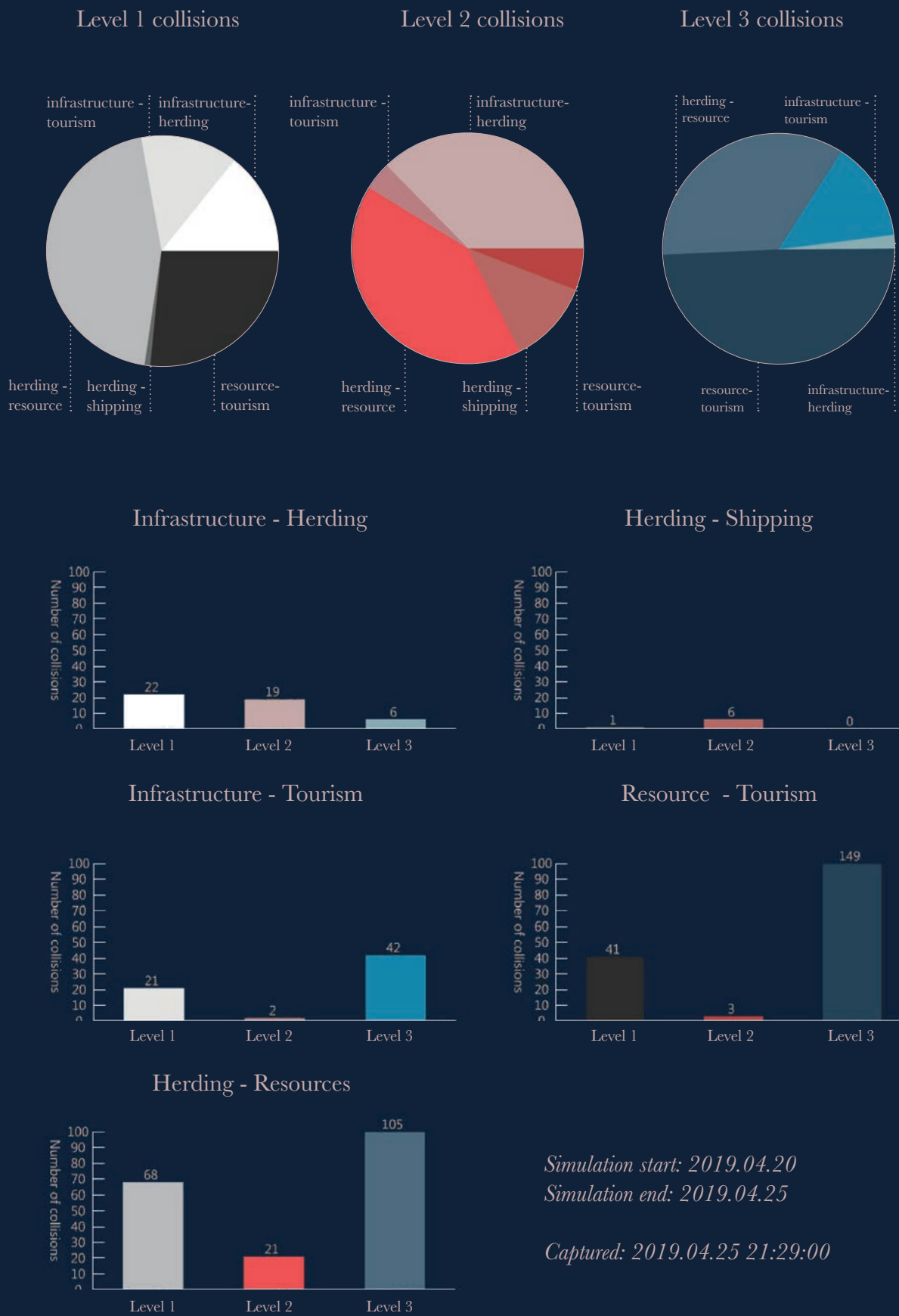


Figure 24. A snapshot from a supporting display showing the number of collisions and ratio among different agent pairs.

Spatial narratives	Level I		Level II		Level III	
<b>Infrastructure</b> <b>Herding</b>	Attribute	Arctic Ocean Rail-way project	Attribute	Railway track	Attribute	Train
	Attribute	Herding dirstrict	Attribute	Grazing areas/ migration path	Attribute	Herd
	Condition	If a railway project goes through the herding district, count 1 collision.	Condition	If a grazing area or migration path overlaps with a railway track, count 1 collision.	Condition	If a herd is closer than 200 m to a moving train, count 1 collision.
<b>Infrastructure</b> <b>Resources</b>	Attribute	Arctic Ocean Rail-way project	Attribute	Railway track	Attribute	Train
	Attribute	Resource potential area	Attribute	Mine teritory	Attribute	Mine pit
	Condition	No collision Complimenting interaction	Condition	No collision Complimenting interaction	Condition	No collision Complimenting interaction
<b>Infrastructure</b> <b>Tourism</b>	Attribute	Arctic Ocean Rail-way project	Attribute	Railway track	Attribute	Train
	Attribute	Tourism destination	Attribute	Resort teritory	Attribute	Resort, tourist agent
	Condition	If a railway project is closer than 20 km to a tourism destination, count 1 collision. Complimenting interaction, too	Condition	If a railway track overlaps with a resort teritory (10 km radius), count 1 collision. Complimenting interaction, too	Condition	If the train is in the resort teritory, count 1 collision.  Complimenting interaction
<b>Infrastructure</b> <b>Shipping</b>	Attribute	Arctic Ocean Rail-way project	Attribute	Railway track	Attribute	Train
	Attribute	Port project	Attribute	Port teritory	Attribute	Port
	Condition	No collision Complimenting interaction	Condition	No collision Complimenting interaction	Condition	No collision Complimenting interaction
<b>Herding</b> <b>Resources</b>	Attribute	Herding dirstrict	Attribute	Grazing areas/ migration path	Attribute	Herd
	Attribute	Resource potential area	Attribute	Mine teritory	Attribute	Mine pit
	Condition	If a resource potential area overlaps with the herding district, count 1 collision.	Condition	If a grazing area or migration path overlaps with the mine teritory, count 1 collision.	Condition	If a herd is in the mine's teritory, count 1 collision (every 30 min).

*Figure 25. Table presenting collision calculation rules among different agent pairs in three different levels.*

Spatial narratives	Level I		Level II		Level III	
<b>Herding Tourism</b>	Attribute	Herding district	Attribute	Grazing areas/ migration pathy track	Attribute	Herd
	Attribute	Tourism destination	Attribute	Resort area	Attribute	Resort, tourist agent
	Condition	No collision Complimenting interaction	Condition	No collision Complimenting interaction	Condition	No collision Complimenting interaction
<b>Herding Shipping</b>	Attribute	Herding district	Attribute	Grazing areas/ migration path	Attribute	Herd
	Attribute	Port project	Attribute	Port teritory	Attribute	Port
	Condition	If a port project is in the herding district, count 1 collision	Condition	If a grazing area or migration path overlaps with a port teritory (5 km radius), count 1 collision.	Condition	If a herd is in the port's territory (5 km radius), count 1 collision.
<b>Resource Tourism</b>	Attribute	Resource potential area	Attribute	Mine teritory	Attribute	Mine pit
	Attribute	Tourism destination	Attribute	Resort teritory	Attribute	Resort, tourist agent
	Condition	If a resource potential area overlaps with a tourism destination, count 1 collision.	Condition	If a mine teritory overlaps with a resort teritory (10 km radius), count 1 collision.	Condition	If a tourist agent is closer than 1 km to a mine pit, count 1 collision.
<b>Resource Shipping</b>	Attribute	Resource potential area	Attribute	Mine teritory	Attribute	Mine pit
	Attribute	Port project	Attribute	Port teritory	Attribute	Port
	Condition	No collision Complimenting interaction	Condition	No collision Complimenting interaction	Condition	No collision Complimenting interaction
<b>Shipping Tourism</b>	Attribute	Port project	Attribute	Port teritory	Attribute	Port
	Attribute	Tourism destination	Attribute	Resort teritory	Attribute	Resort, tourist agentnt
	Condition	No collision Complimenting interaction	Condition	No collision Complimenting interaction	Condition	No collision Complimenting interaction

in certain time intervals depending on the dynamic agents' speed (dynamic with static).

### *Collision maps*

The dynamic collision maps display occurring collision distribution over time and in different locations (see Figure 26).

Different time intervals for collision maps can be chosen: immediate collisions (counted for a short period of time, e.g. one cycle, one hour) or accumulated collision maps (over one day, week, month or year). Generating collision maps at different times can inform about different characteristics the same space have. For example, collision maps generated at four different times of reindeer grazing cycle show which collision areas are present throughout the year and which ones are reoccurring (see Figure 27).

Defining collisions in different levels allows to easier distinguish which agent species are conflicting — conceptual, physical or dynamic — and at which time. However, all levels are strongly interconnected and interdependent, i.e. changing one will impact other collision levels. The railway track itself is not harmful to the reindeer. It is only the train that moves along the tracks that cause major collisions with reindeer causing traffic accidents and animal loss. However, removing the railway tracks also eliminates trains and any possibility of train-reindeer collisions. Therefore, collision situations happening at one level can be reduced by making changes in another level.



*Parameter values captured 2019.04.25:*

***level 3 collisions: 302***

*plane agent : airport 2018*

*train agent: 1 daily*

*herd agent:*

*summer migration start: 2019.04.20*

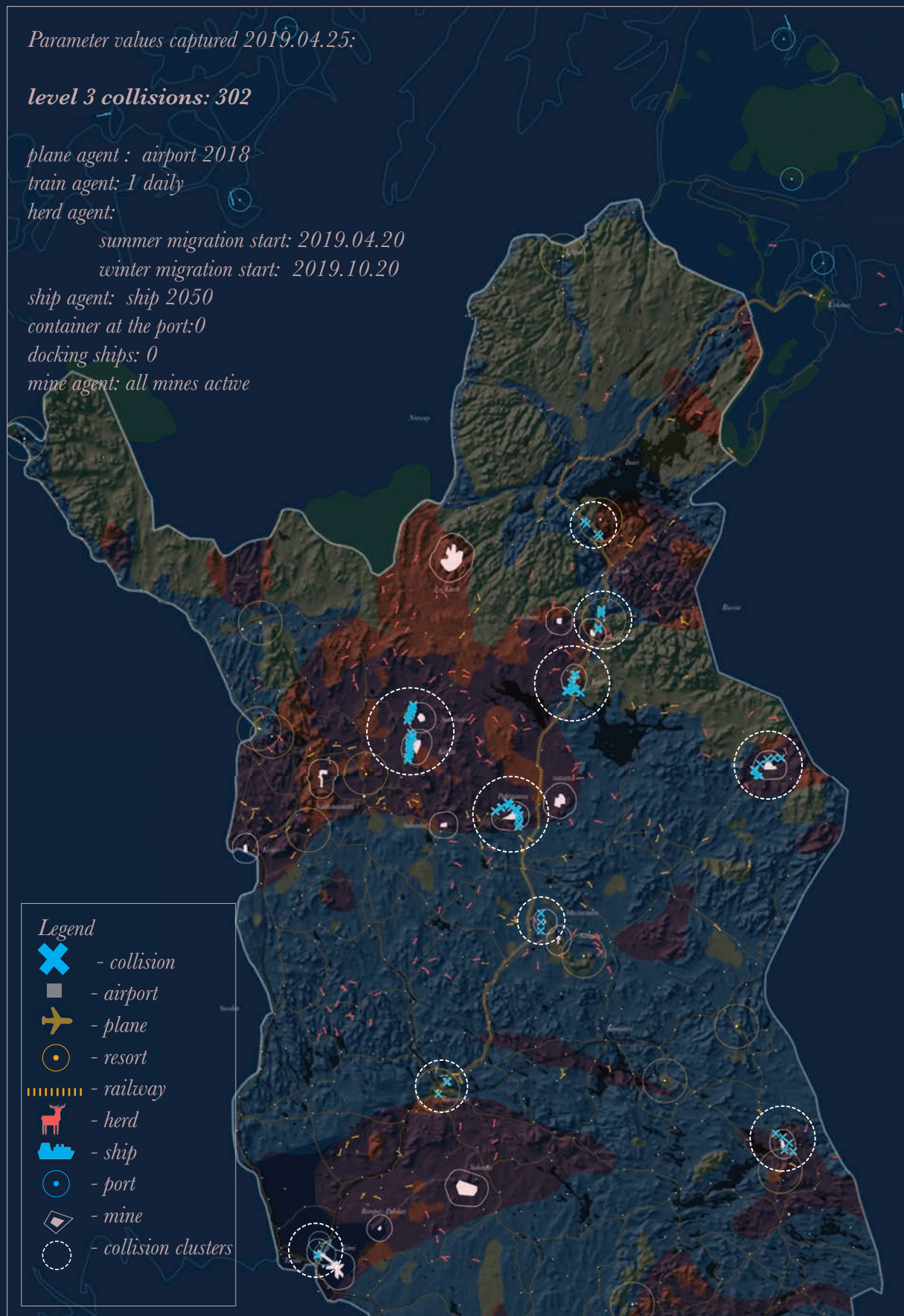
*winter migration start: 2019.10.20*

*ship agent: ship 2050*

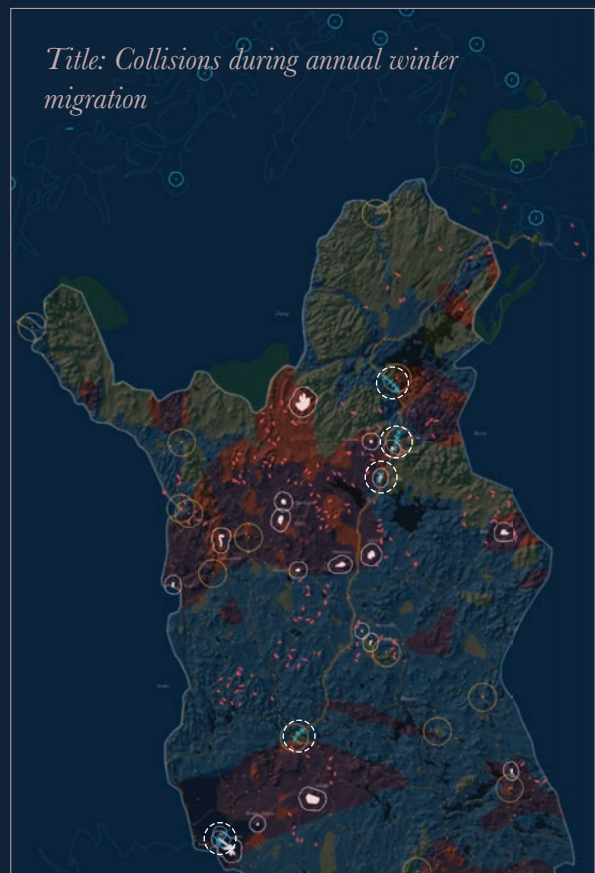
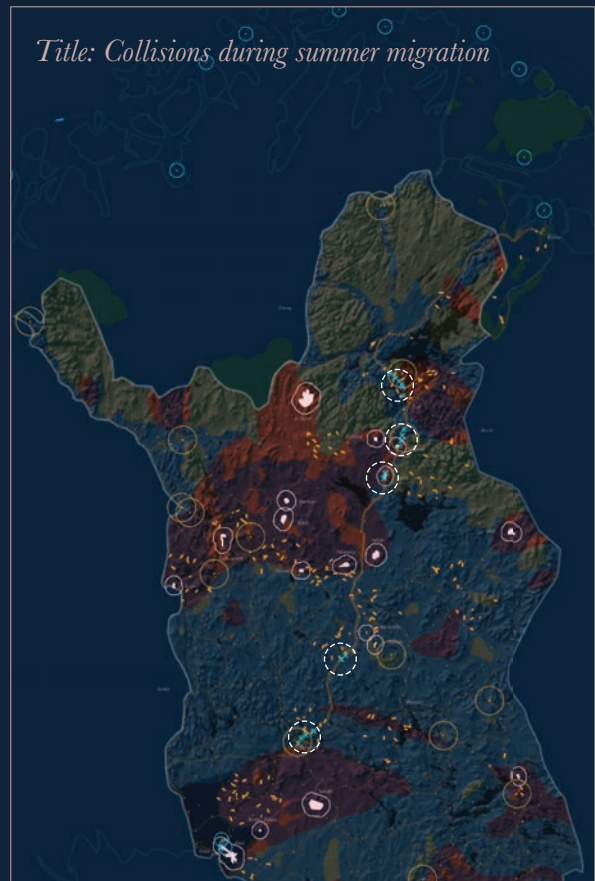
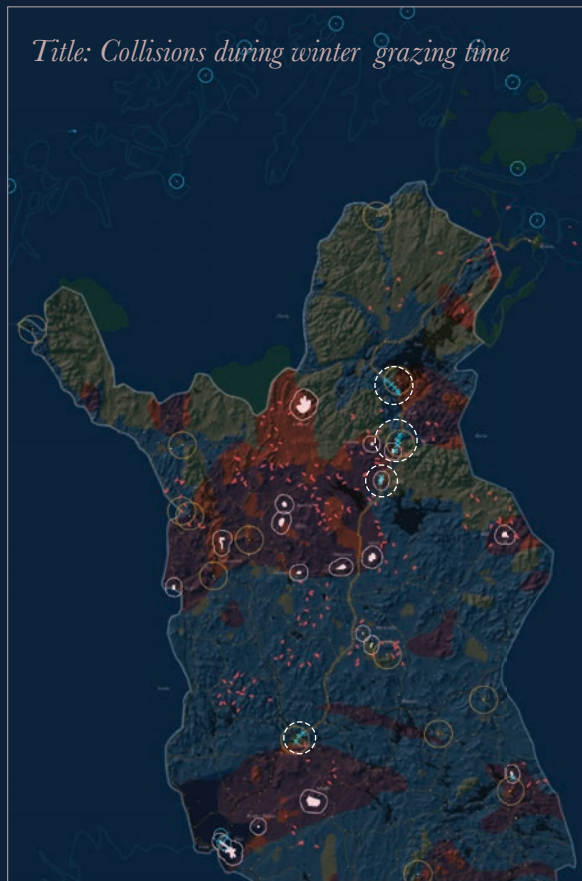
*container at the port:0*

*docking ships: 0*

*mine agent: all mines active*



*Figure 26. Snapshot from a running simulation model. Level 3 collisions were gathered over 5 days in the simulation (04.20-04.25).*



*Figure 27. Images are captured from a running simulation model at different dates throughout the year, showing the amount of daily occurring collisions and their location.*

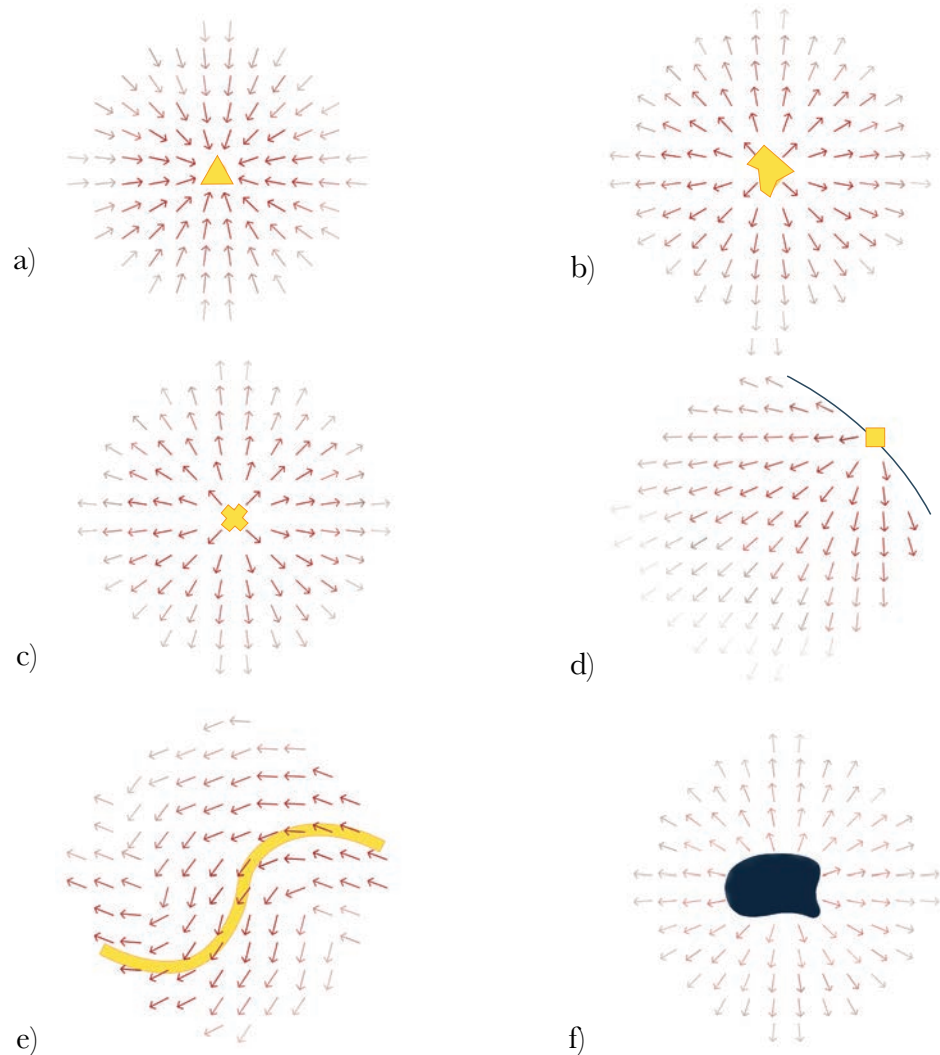


### Defining direction vector maps

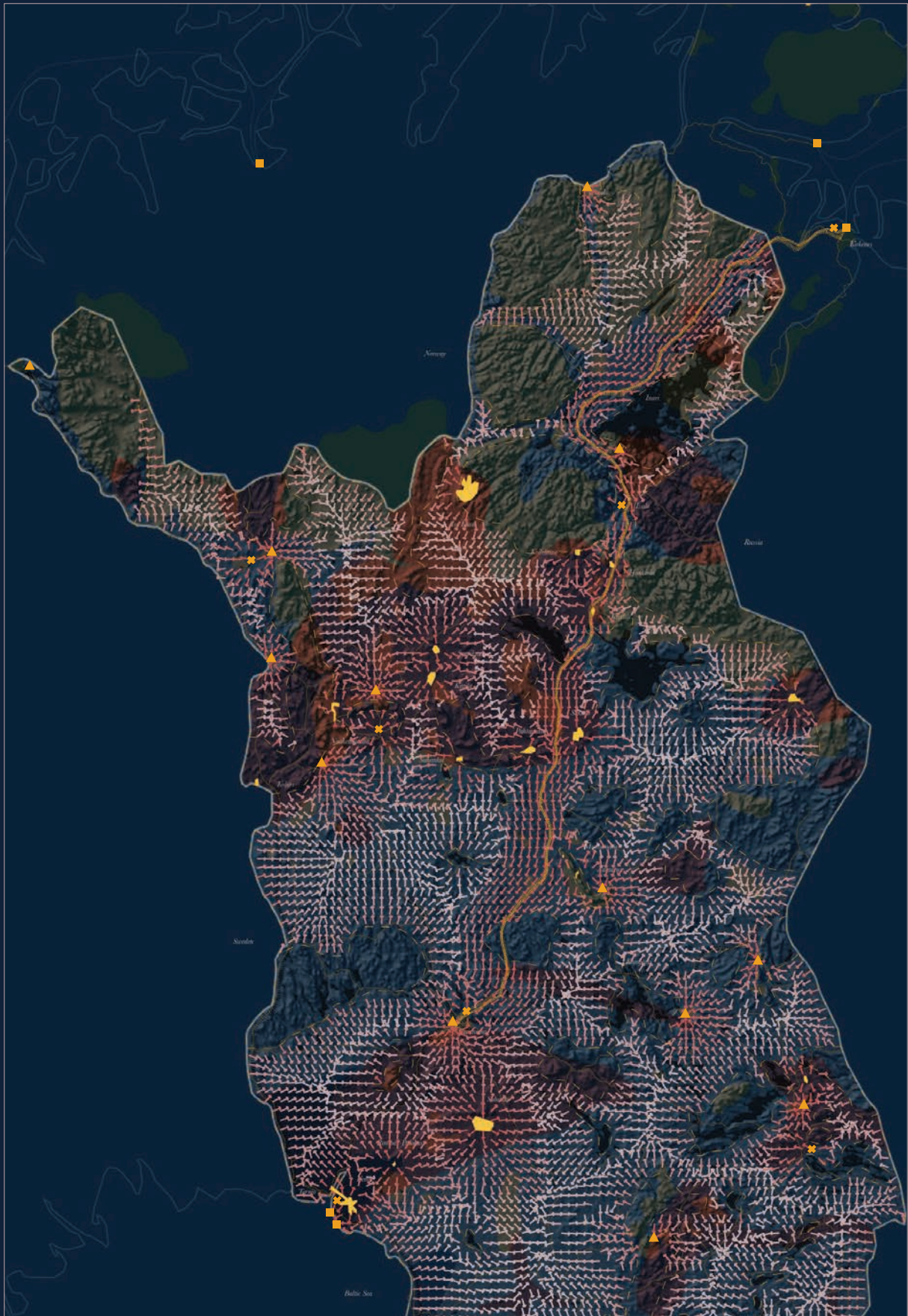
Creating a vector field is the assignment of a vector to each point in a subset of space (Hubbard & Hubbard, 1998). It can represent flows, diffusion, pollution, erosion, migration and many other natural and social phenomena, making it a versatile tool for analysis. Vectors can be defined by its magnitude and direction (Li & Hodgson, 2004).

In the developed model, each agent, static or dynamic, has a direction as one of its attributes (see Figure 28). However, the direction of an agent often goes beyond its physical boundaries affecting the surroundings. For example, a mine, depending on the type and phase, can spread dust on vegetation, create noise, contaminate soil, increase erosion and deforestation processes or affect a reindeer's weight gain (Reindeer Herder's Association, 2014).

The dynamic agents' movement in space through and within Level 2 agents (mines, resorts, airports) requires an effort. For example, tourists move with no effort around airports, but it gets difficult to move around mines in the same way. This increased effort becomes an underlying reason for emerging conflicts in the Finnish Lapland. The necessary effort for these movements can be calculated involving vector algebra (Li & Hodg-



*Figure 28. Diagram showing the source vectors for different agent types: a) resorts b) mines c) airports d) ports e) railway f) topography obstacles.*



*Figure 29. Map showing the generated vector field based on the Level 2 agents' and topographical elements' source vectors*

son, 2004). In this thesis, the direction analysis is based on the difference between the moving agents' direction vector and a vector field along the agents' path.

The analysis of direction patterns can improve understanding about often invisible structure that create specific spatial conditions and effects on agents, e.g. reindeer avoiding mining territory or weight loss due to being exposed to increased noise, pollution or loss of pasture area.

By observing the dynamic agent's movement, one can reconstruct the structure or vice versa. Analysing the invisible directional impact on space and agents can support planners and designers in locating various agent sources or destinations, like airports and resorts, and help to shape the mobility network.

#### *Direction vector maps*

The vector field, defined earlier, was used to create the direction vector map for the Finnish Lapland (see Figure 29). The source vectors that generate it are the impact directions of Level 2 agents: mines, resorts, ports, airports and railways. Direction attributes of topographical elements, like slopes, hills and water areas, were also used as source vectors. Here, source vectors are generated perpendicular to the boundary pointing away from the topographical element, representing movement away from the obstacle (see Figure 28).

Additionally, supporting monitor can display the agent's path and movement effort values along it (see Figure 30).

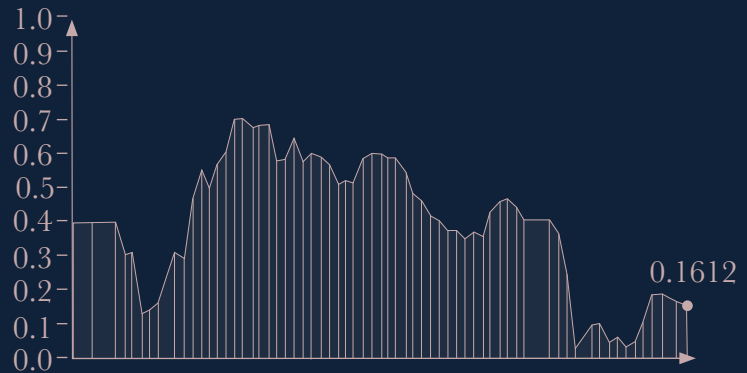
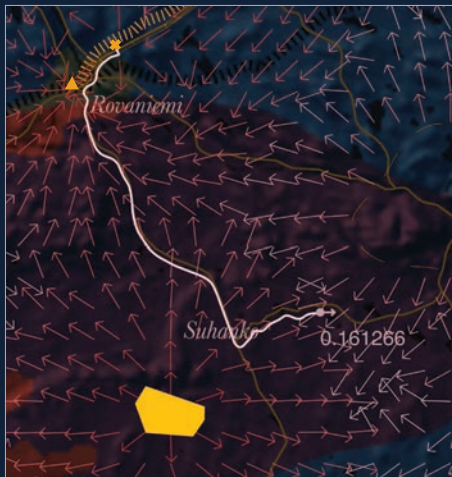
Increasing or decreasing vectors' lengths create different graphics, but its visual impact is not further detailed. Instead, different colour coding was used to differentiate the vectors' magnitude that is based on proximity to the source vectors and their direction. Level 2 agents are assigned different impact weights on the vector field, further affecting the overall outcome. For example, while Kittilä mine has an impact weight of 1.0 (maximum) due to its intense activities, Enontekiö airport has assigned a weight of 0.3 due to its low flight frequency.

It is worth mentioning that the generated direction vector map displays a "soft" vector field, i.e. vectors are arranged in a gradient manner which blurs case-specific situations, due to the regional scale of the Finnish Lapland. To create a more detailed direction vector map, principles of how to assign vectors in situations where elements with isolated directions occur, e.g. bridges, tunnels, fenced railway tracks or highways, need to be further developed. In a smaller scale, these case-specific directions might significantly affect the final output.

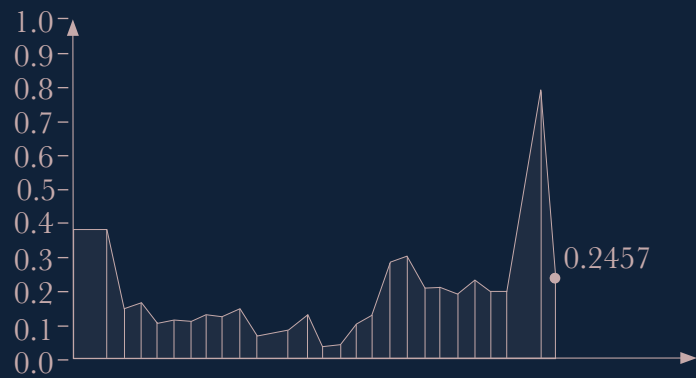
This model output attempts to combine directions of agents from different spatial narratives instead of separating them by type. For example, infrastructure agents' directions are combined with tourism and resources' directions.



### Train passenger agent path



### Plane passenger agent path



### Herd agent path

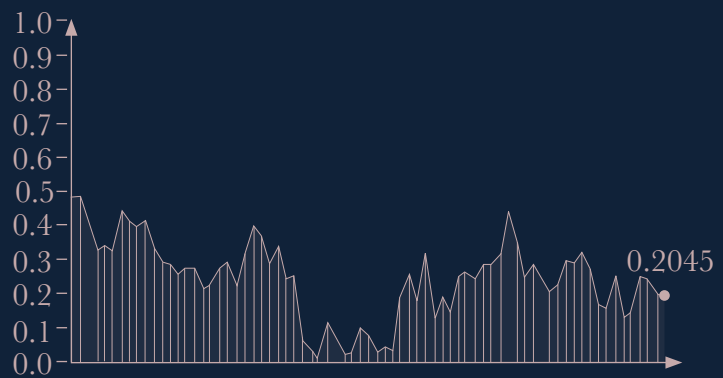


Figure 30. Snapshots showing the movement effort of different agents along the path.

# Chapter 7

## *Reflections*

*Designing a simulation model is a challenging endeavour, requiring a deep theoretical and practical understanding of how systems and behaviours work and can be implemented in a digital environment.*

*The designed model is expandable. While five spatial narratives were included in this thesis work, the design could also work with two or even ten narratives. The selection should be based on the problem that the model tries to address.*

*The most demanding step that requires critical thinking as a designer is the careful translation of the agents' behaviour into computational parameters and linking the causality of certain phenomena with specific agent behaviour or condition.*

*Finally, concepts like collisions and vector fields require further critical assessment and development to advance the use of the designed simulation model.*

# Chapter 8

## *Intro*

*The experiment chapter documents three different generic experiment setups. Its goal is to demonstrate the potentials the proposed decision support tool has for large-scale planning and design purposes.*

*The presented generic experiments show scenarios of how the Arctic Ocean Railway could be assessed with time and direction patterns.*

*Finally, during the experiment the important, but otherwise invisible, links and interactions between agents are displayed. This chapter introduces several strategies to represent and interpret these interactions.*

## 8. The Experiment

### 8.1 The potential uses of the simulation model

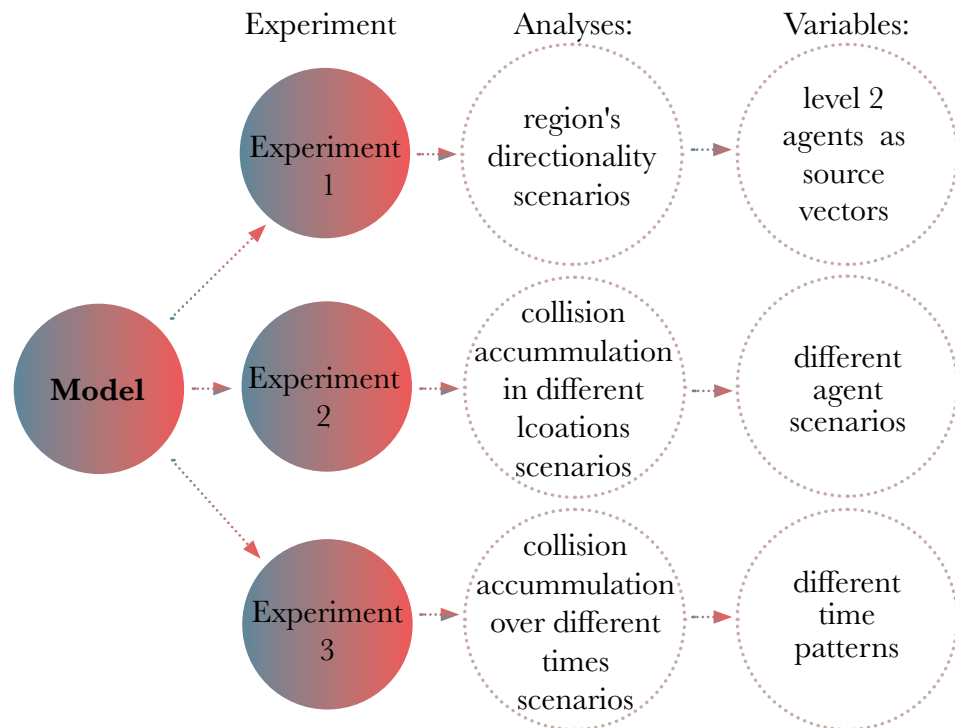
Three generic experiments were carried out in order to test the simulation model's workflow and present its potential uses for decision-making support in planning and design tasks.

These three experiments show possible strategies to test different scenarios of a regions' directionality by generating and observing vector fields and its impact on agents, or strategies to test varying time patterns and to observe the collision accumulation (see Figure 31).

Experiment 1 analyses the direction vector field output that is based on included Level 2 agents as source vectors. Experiment 2 analyses generated collision maps with the same agent and time pattern but at different locations. Finally, Experiment 3 analyses generated collision maps with the same agent and location but with different time patterns.

The outputs of each experiment are the generated collision or direction vector maps. A set of variables are kept consistent throughout all experiments (model environment boundaries, number of points on which the vector field is generated, Level 2 agents' directions), while other variables were changed (agents' schedules, locations, Level 2 agents' inclusion in the model).

The general setup for the experiment consists of 3 parts: 1) choosing the parameters to test 2) running the simulation model in the GAMA platform Rhino/Grasshopper software 3) visualising results as outputs.



*Figure 31. Diagram showing the analysed subjects and changed variables behind the three experiments described in this chapter.*

## 8.2. Experiment 1

### *Changing the sources of the default vector field*

As mentioned in Chapter 7, the default vector field is generated using the Level 2 agents' directions. Adding or removing single agents or groups of agents changes the vector field arrangement, e.g. a new mine in the area gives new directionality to space. Experiment 1 investigates how placing and removing different Level 2 agent species changes the final direction vector map (see Figure 32).

In the first test, Level 2 mine agents' directions were not included as sources for the default vector field.

In the second test, the Arctic Ocean Railway was removed as a source for the default vector field to test what directionality it introduces in the surrounding environment.

In the third test, the resort agents' directions were not included as source vectors to test how tourism affects the region's spatial directionality.

### *Results*

A path-like pattern can be seen in all tests. It is occurring where two different directionalities collide. In the case of mines and resorts, they create a directional flow when close to each other.

From the first test, it can be seen that placing mines in the region creates a denser pattern-like structure (see Figure 32 b)). Since mines have direction outwards, they will likely push specific agents away.

The second test shows that railway directionality is strongly dominating and breaks the overall direction field map, otherwise continuous, path-like pattern (see Figure 32 a & c)).

In Figure 32 d) we see that placing resorts can break the path-like pattern since their directionality matches with one of the opposing directions that create such a pattern.

The direction maps also show, where the homogeneity of the default vector field is most visible and which combinations of agents break or densify the path-like pattern.

### *Reflections*

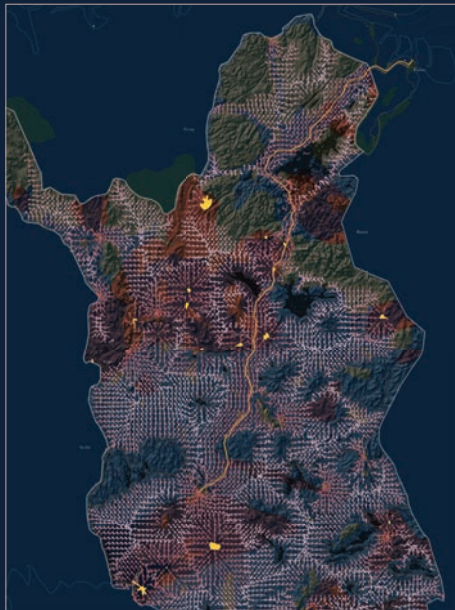
Generally, the more sources are included in the vector field, the denser path-like pattern likely will be generated.

The topographical constraints also play a role in shaping the default vector field, but their impact is not strong due to low impact weight. Its colour is, therefore, light in the figures.

Finally, the observed path-like pattern could work as a passage for specific agents that would avoid one or many level 2 agents.

This type of experiment informs about the underlying structure and how likely agents would move in space based on friction levels they would encounter.



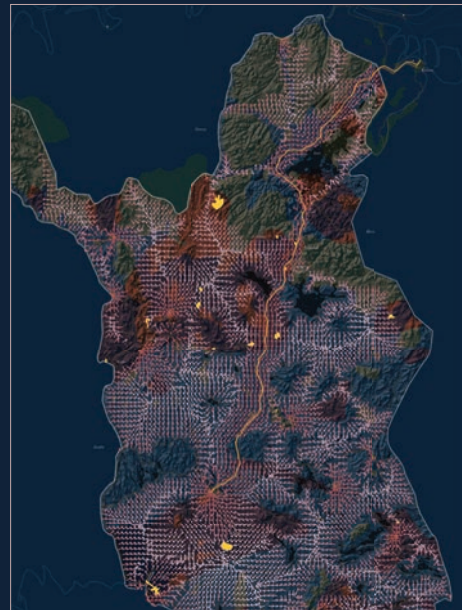


a)  
Source vectors:

Mines  
Airports  
Railway  
Ports  
Resorts  
Water areas  
Slopes

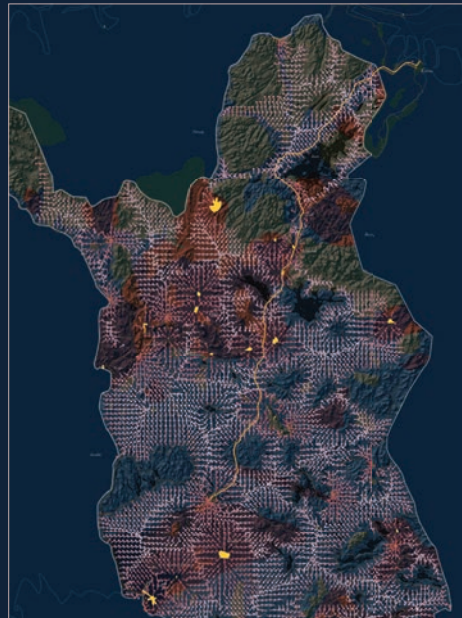
b)  
Source vectors:

Airports  
Railway  
Ports  
Resorts  
Water areas  
Slopes



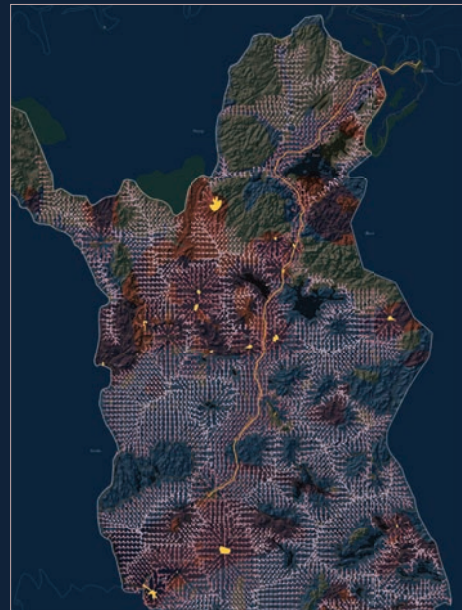
c)  
Source vectors:

Mines  
Airports  
Ports  
Resorts  
Water areas  
Slopes



d)  
Source vectors:

Mines  
Airports  
Railway  
Ports  
Water areas  
Slopes



►  
*Figure 32. Experiment 1 results: a) default vector field portraying the speculative situation if the Arctic Ocean railway is built b) mines are not included as source vectors c) the Arctic Ocean Railway is not included as source vectors d) resorts are not included as source vectors*

### 8.3. Experiment 2

#### *Changing the Arctic Ocean Railway route*

Since the beginning of the Arctic Ocean Railway project, multiple routes were under consideration. As presented in Chapter 3, the Rovaniemi-Kirkenes route was chosen as the most potential and the one to proceed in discussions between governmental, cultural, ethnical and business stakeholders.

Experiment 2 investigates three alternative railway routes between the two cities while keeping the rest of the variables the same. It examines the number of collisions three routes would generate over the same time period (see Figure 33).

Route 1 is the original route presented in the previous chapters, following highway A4 and going through Sodankylä, along the northern coast of Inari lake, passing Näätämö before crossing the Finnish-Norwegian border and reaching Kirkenes.

Route 2 first passes by Kimijärvi before it reaches Sodankylä and goes along the eastern side of Inari lake passing by Nellim and following the Finland-Russia and Finland-Norway borders before it reaches Kirkenes.

Route 3, instead of Sodankylä, passes by Kittilä and follows the regional road 955 up north, passing by the Hammastunturi Wilderness Area and Lemmenjoki National park and Utsjoki before crossing the Finnish-Norwegian border where it follows E6 highway to Kirkenes.

#### *Results*

Overall, Route 2 (see Figure 33 b)) generated the most collisions (37), while Route 1 (see Figure 33 a)) the least (23). All routes created collisions in the Rovaniemi area, but the number and distribution along the track differ. Routes 2 and 3 created three locations, where multiple collisions clustered. Meanwhile, Route 1 resulted in five places where collisions occurred but with fewer collisions per location.

Furthermore, Route 1 and 2 caused no collisions on the first half of the railway track, but both generated collisions around the Inari lake area. Meanwhile, Route 3 invoked collisions only near Kittilä and at the Finnish-Norwegian border (see Figure 33 c)).

Collisions mainly happened between train passengers and mining territories, and between train and herd agents.

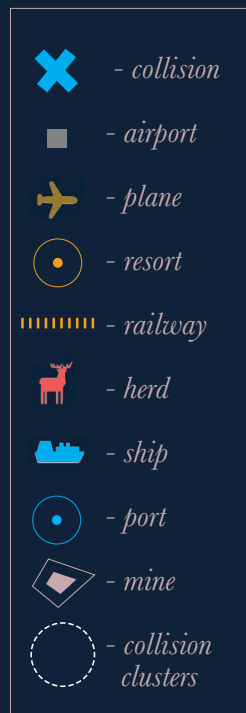
#### *Reflections*

Experiment 2 shows how different options of the same agent with the same schedule can vary in collision numbers, as well as, in their distribution along the route.

The comparative analysis of the three routes helps to better understand the impact of the same railway project in its different scenarios.

If repeated at different dates, the experiment might also help to uncover the areas that have the least collision chance in the long term.

# Legend

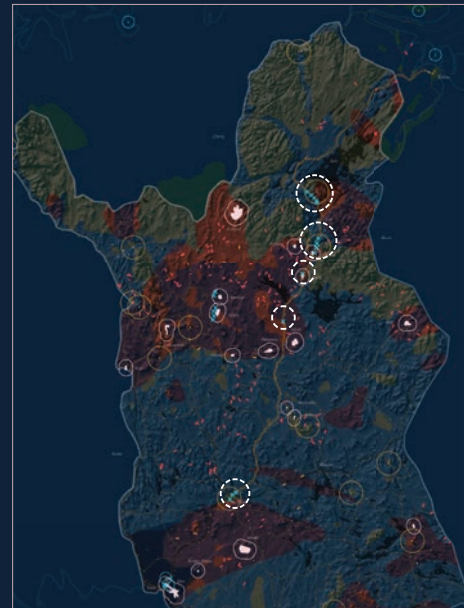


a)

Route 1:

Rovaniemi-Sodankylä-Kirkenes

Level 3 collisions: 23

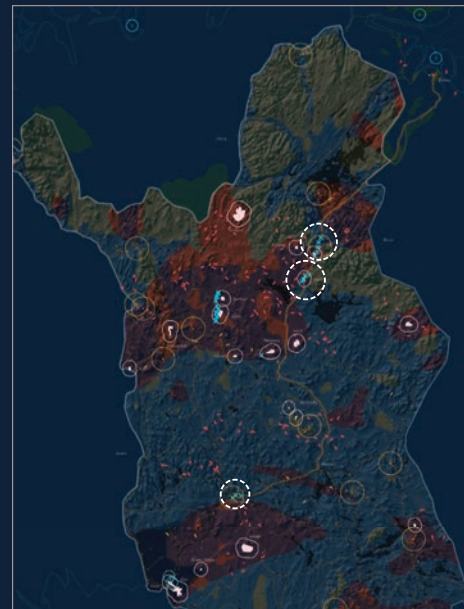


b)

Route 2:

Rovaniemi-Kemijärvi-Kirkenes

Level 3 collisions: 37



c)

Route 3:

Rovaniemi-Kittilä-Utsjoki-Kirkenes

Level 3 collisions: 34

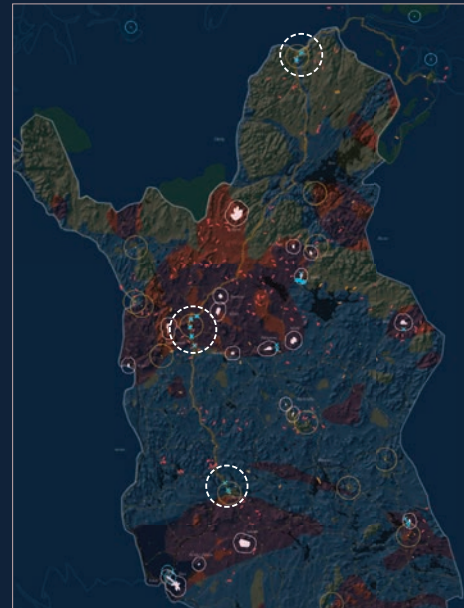


Figure 33. Snapshots of the running simulation visualizing the Level 3 collisions generated by the different routes.

## 8.4. Experiment 3

### *Changing the train schedule frequency*

The schedule frequency can be an indicator of the agent's presence in space. For example, train schedules play a crucial role in generating Level 3 collisions. Changing the time of the day when the train departs from Rovaniemi and Kirkenes and its frequency allows to investigate the time pattern role in generating collisions.

Three scenarios were tested: one, two or three daily passenger trains departing from Rovaniemi at chosen times: 9:30 am, 12:00 am and 5.00 pm. It is worth mentioning that each train has the same amount of passengers, which in a real-world situation might differ depending on the scheduled time.

Experiment 3 shows a possible way to examine the impact of the agent's presence in space through its schedule (see Figure 34). Similar tests could be done with a mine's life cycle or the reindeer grazing cycle.

### *Results*

The created maps show that the train schedule affects space. Test results show that the same route tended to cause collisions to cluster around the same locations despite the number of daily trains. Furthermore, the railway scenario causes a certain number of collisions despite the frequency since the results from 1, 2 or 3 daily trains vary mildly.

Based on results, one daily train (see Figure 34 a)) has fewer locations where collisions cluster.

The tests show that the higher the frequency, the more collisions are generated but not necessarily in the same locations.

### *Reflections*

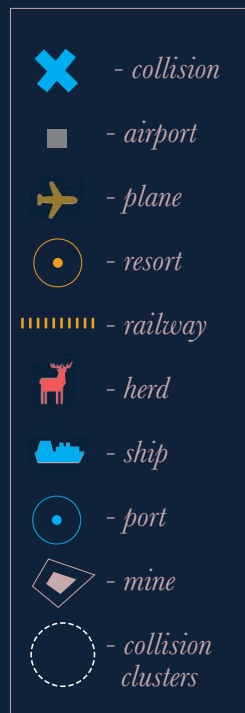
Analysing schedules can work as an informative method because it uncovers different features of the same location and agents over time, i.e. how specific times are associated with more or fewer collisions. Identifying those temporal-spatial characteristics could support choosing the train's future schedules.

This generic experiment illustrates how reoccurring agents can cause temporal collisions that are created not because of location qualities but because of the agent's schedules. This location, therefore, can be represented through reoccurring agent collisions.

Furthermore, in the experiment, the train's passenger capacity was kept the same. This might differ from a real-world situation. Some travel times are more popular among passengers than others. Therefore, days can also be profiled with a higher and lower number of collisions based on the passengers' preference for travelling time.



## Legend



a)

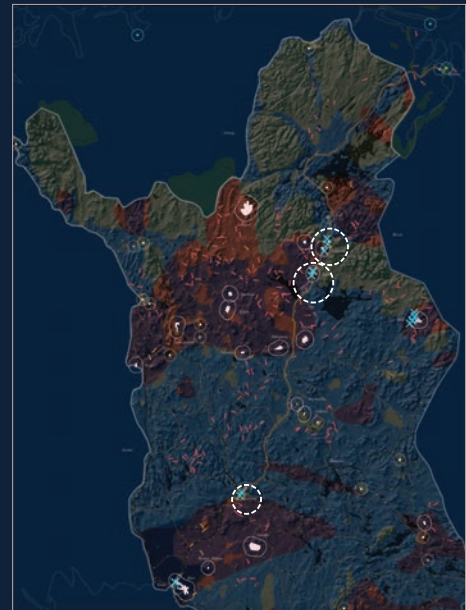
1 daily trains

Simulation start date:  
19.04.2019 11:59 pm

Simulation end date:  
20.04.2019 11:59 pm

train 1: 09:30 am

Level 3 collisions: 18



b)

2 daily trains

Simulation start date:  
19.04.2019 11:59 pm

Simulation end date:  
20.04.2019 11:59 pm

train 1: 09:30 am

train 2: 12:00 am

Level 3 collisions: 26



c)

3 daily trains

Simulation start date:  
19.04.2019 11:59 pm

Simulation end date:  
20.04.2019 11:59 pm

train 1: 9:30 am

train 2: 12:00 am

train 3: 5:00 pm

Level 3 collisions: 31

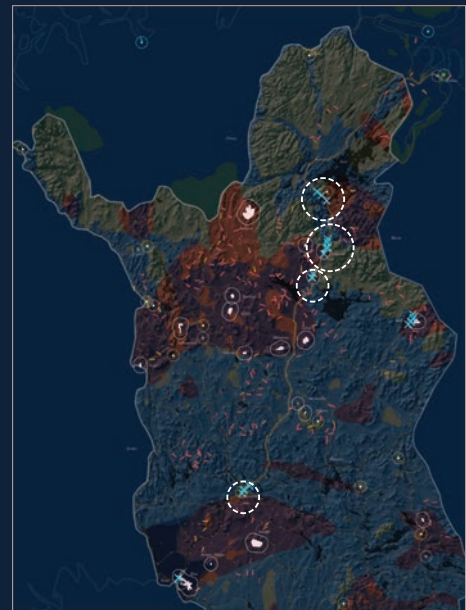


Figure 34. The images portray the collision maps generated from one, two or three daily passenger trains.



# Chapter 8

## *Reflections*

*Within chapter 8, several approaches to evaluate possible spatial transformations using direction vector and collision maps have been introduced.*

*Complex content of the simulation model and outputs give multiple ways to analyse the spatial consequences of each planning decision. The gained insight increased with each iteration and built on the user's interpretation of the phenomena. Therefore, carrying more experiments helps to build on design intuition.*

*However, reasoning and sense-making of the results need to be further assessed. In order to better evaluate the potential of the presented generic experiments, it should be compared with the classical planning strategies.*

*Finally, the model holds more strategies to evaluate spatial situations that is not discussed in this thesis.*

# Chapter 9

## *Intro*

*The CityScope Lapland chapter introduces the process of facilitating a tangible user interface setup through the CityScope framework, developed by MIT Media Lab researchers. The chapter describes how the setup was adjusted to a specific project, namely the case of the Finnish Lapland, and how all parts were combined with the simulation model on a conceptual, as well as, technical level.*

*The Cityscope Lapland table addresses known issues in large-scale planning and design: poor data readability, late stakeholder involvement in the design process, lack of holistic knowledge on the project domain and awareness of a broader context.*

*This chapter presents the final step to support planning decision making — an interactive table as a medium to facilitate and intensify knowledge exchange.*

## 9. CityScope Lapland

### 9.1. Enhancing interaction through CityScope Lapland

The CityScope tangible user interface (TUI) was combined with a simulation model and additional displays to create a decision support tool for planning and urban design tasks, hereafter named CityScope Lapland (see Figure 35).

Running the simulation model on a computer and displaying it on a screen is undoubtedly useful — collision locations, generated vector fields and agent behaviours can be seen. While on a computer, there is likely only one controller of the simulation model to test the ideas, a tangible user interface allows multiple users to participate in collaborative activities.

Placing the model outside of the screen onto one or more tangible interfaces can improve stakeholder's engagement. This is because physical elements one can interact with provide a strong feeling of directness to these interfaces and make them intuitive for novices (Schneider et al., 2011). Furthermore, coupling tangible objects like LEGO® with projected information, as in CityScope Lapland (see Figure 38), allows for a very close mapping between tangible input and digital output; between the physicality of an object and the abstraction of visualisation (Schneider et al., 2011).

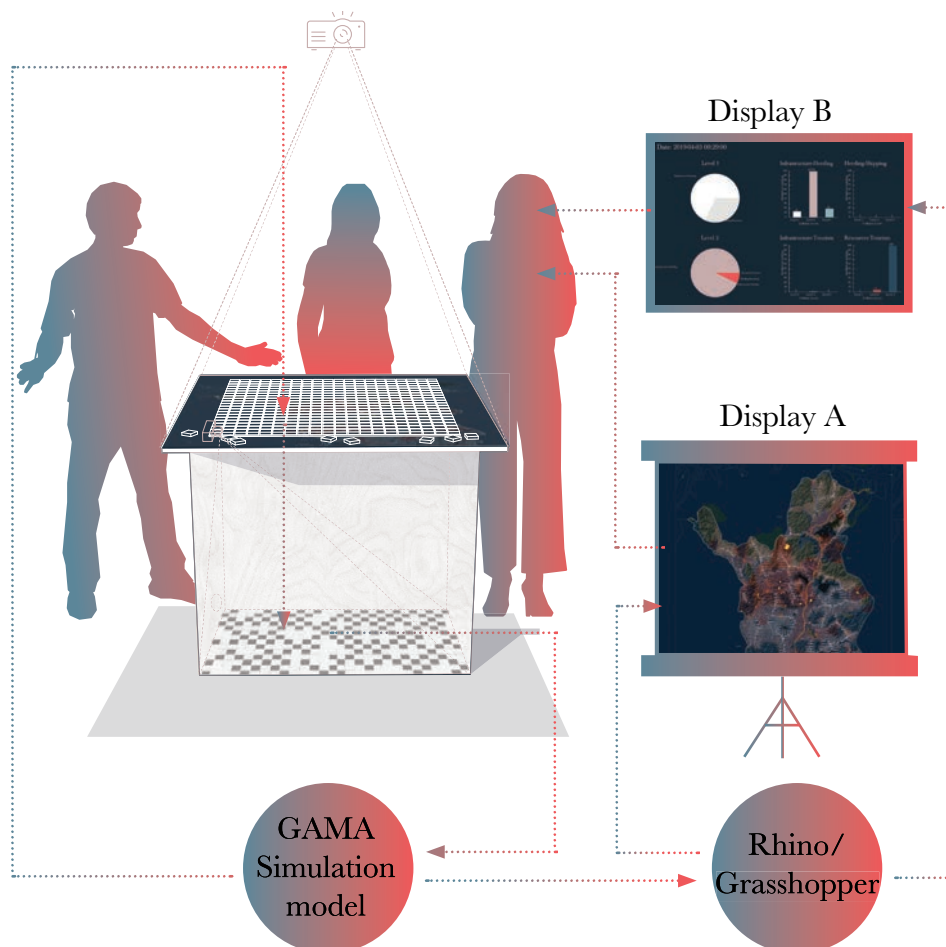
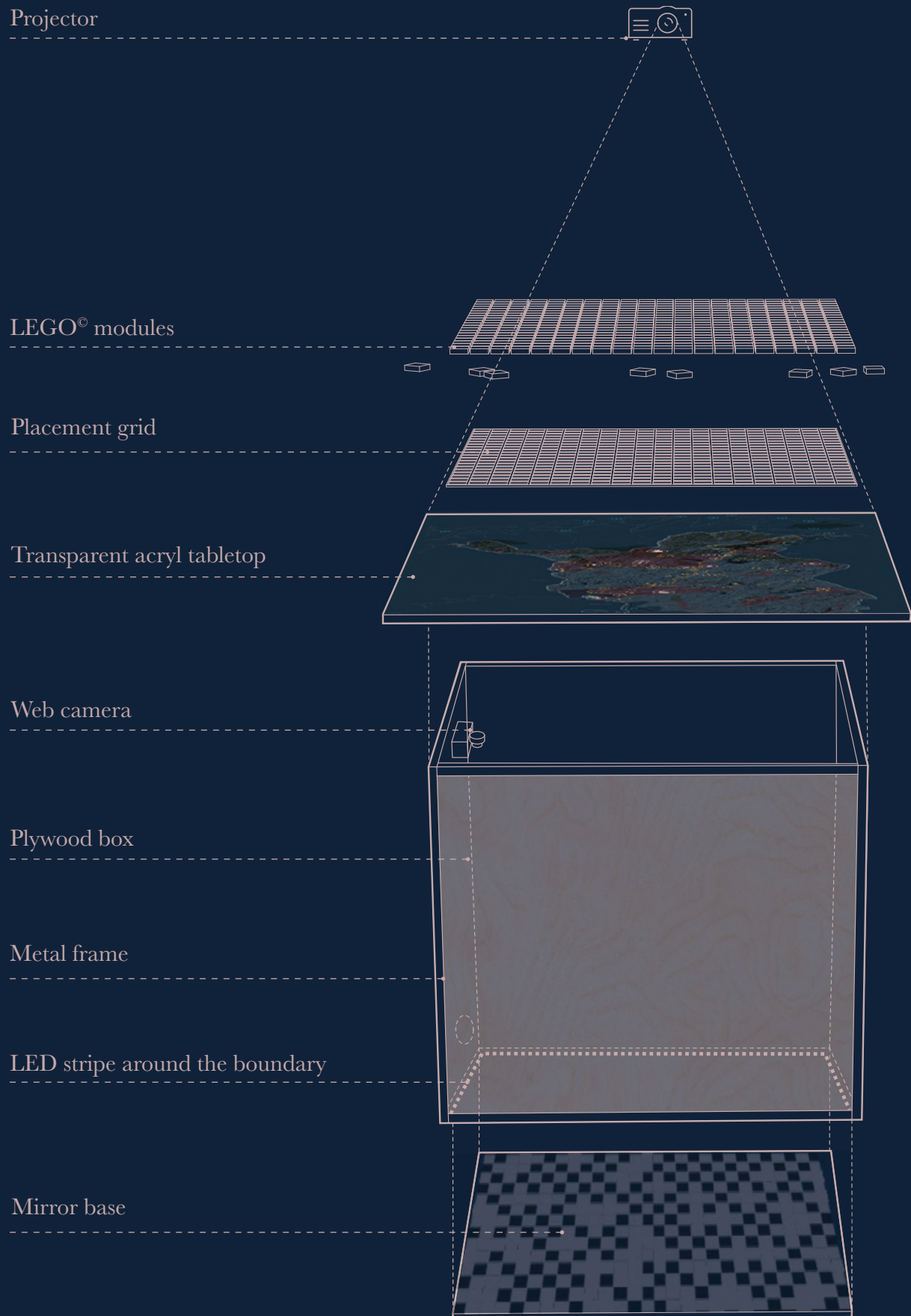


Figure 35. Diagram showing the different parts of the CityScope Lapland planning support tool: the GAMA simulation model, the CityScope Lapland table and two additional displays showing the two main outputs (Display A: direction vector map, Display B: collision map).



*Figure 36. Diagram showing the physical components of the table and its assembly.*

The previous chapters in PART II described the software used in the design of the decision support tool, e.g. pattern implementation in a simulation model and generation of its outputs. This chapter focuses on the physical aspects of the proposed design. It presents the facilitation of the software through the physical CityScope setup and its interactive features (see Figure 36).

A demonstration video showing how software and hardware were combined in the CityScope Lapland tangible user interface and showing interactions with the interface can be found here:

<https://vimeo.com/389396106>

## 9.2. The table

Multiple CityScope physical table setups are available at the Aalto City-Science Lab<sup>1</sup>. The one used for this work has an 1115 mm x 1115 mm display surface and is made from transparent a 20 mm acrylic sheet. A non-transparent grid to place LEGO® modules is glued on top. The interactive area is approximately 20 x 20 4-by-4 LEGO® modules, corresponding to a size of 985 x 985 mm. One tile represents approximately a 10 x 10 km in the real world.

Each LEGO® module has a pattern in the bottom consisting of black and white "pixels" (see Figure 39). If the scanner recognises a pre-defined pattern, a corresponding action is evoked in the simulation model in real-time.

The bottom of the table contains a mirror surface to reflect the patterns of the LEGO® modules helping to achieve more precise scanning (see Figure 40). The table's sides are made of plywood pieces that allow mounting the mirror, tabletop and web camera.

## 9.3. The projector

The projector is placed above the physical table and projects the generated simulation model on the LEGO® tabletop (see Figure 41).

## 9.4. The scanner

A scanner is built using a generic web camera and Python code available at [https://github.com/CityScope/CS\\_CityScoPy](https://github.com/CityScope/CS_CityScoPy). In a scanning mode, the camera records the mirrored view of the LEGO® modules' bottom. For each frame, it applies a grid equivalent to the interactive LEGO® modules' grid (20 x 20 modules). Further, it divides each grid cell into 16 "pixels". By evaluating the pixels' brightness a 0 or 1 is assigned to each pixel corresponding to black and white respectively. Predefined combinations of 1 and 0, so-called tags, represent different parameter values in the simulation model (see Figure 37). When the scanner recognizes a tag, the corresponding value is changed.

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<sup>1</sup> <https://urbanacademy.fi/csl/table/>



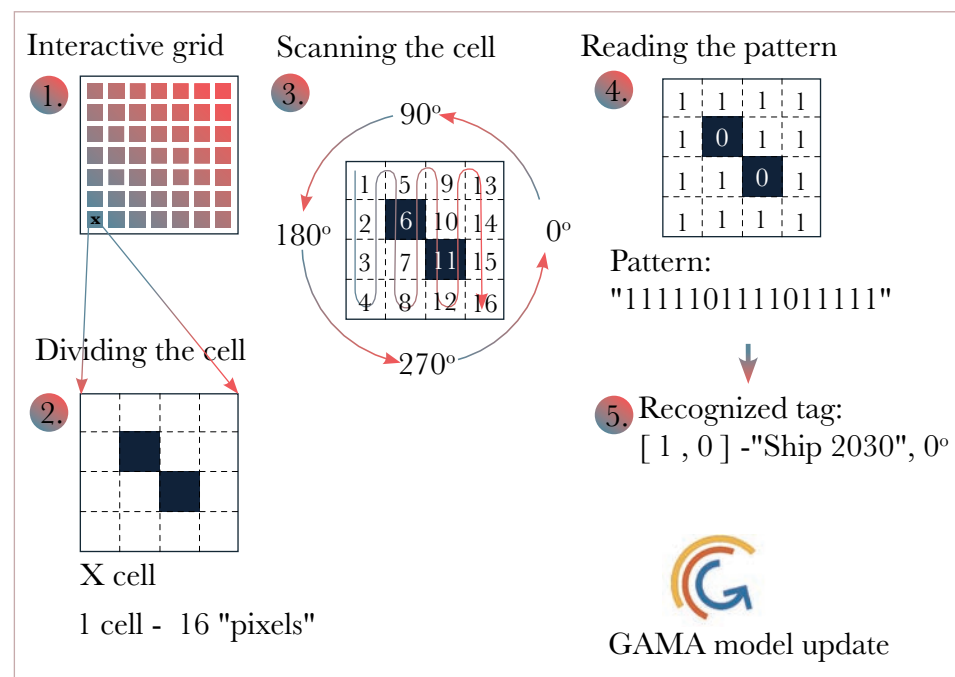
To establish communication between several applications (the GAMA simulation model, the CityScope scanner and Rhino/Grasshopper scripts) the User Datagram Protocol (UDP) was used. It is an alternative communication protocol, defined by an IP-address and a port number. The scanner sends a list of values containing the recognized tags per grid cell, whenever a tag is changing, via UDP to the GAMA simulation model. In this way, by changing LEGO® modules in each cell, the user can immediately interact with the simulation model.

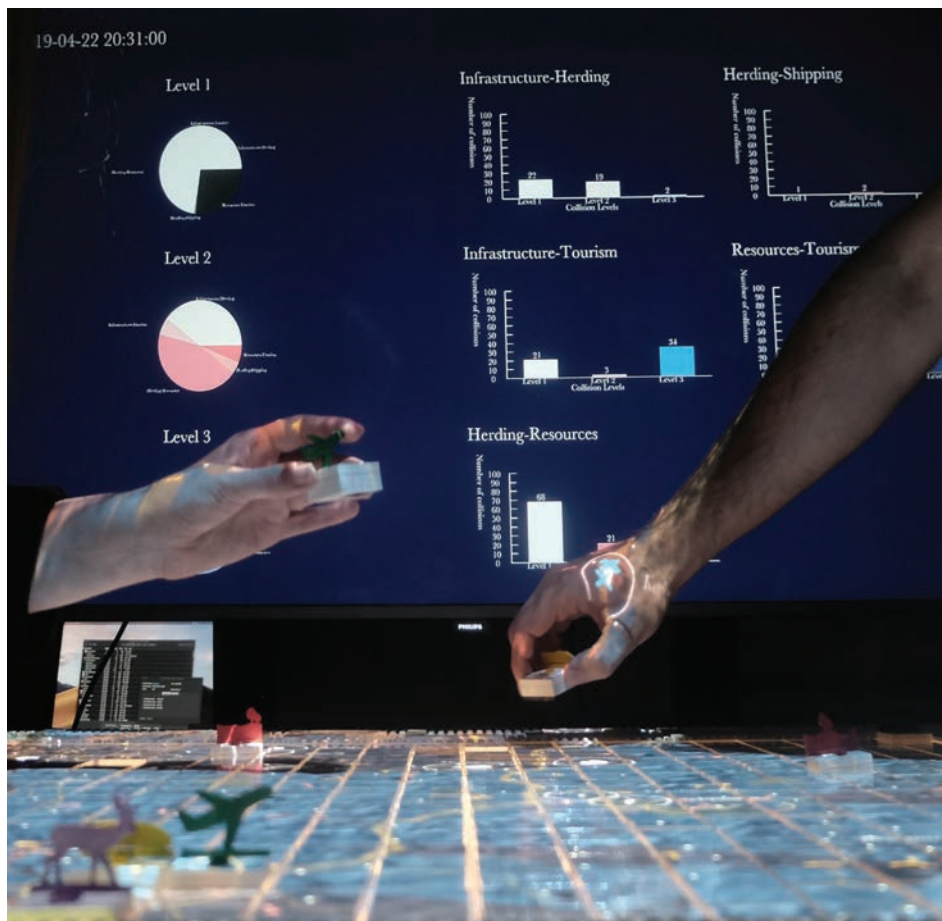
### 9.5. Additional displays

Apart from the table itself, additional displays are used (see Figure 35). This allows better readability by not overloading the table projection with information. Thereby a broader view of the on-going processes in the simulation can be observed.

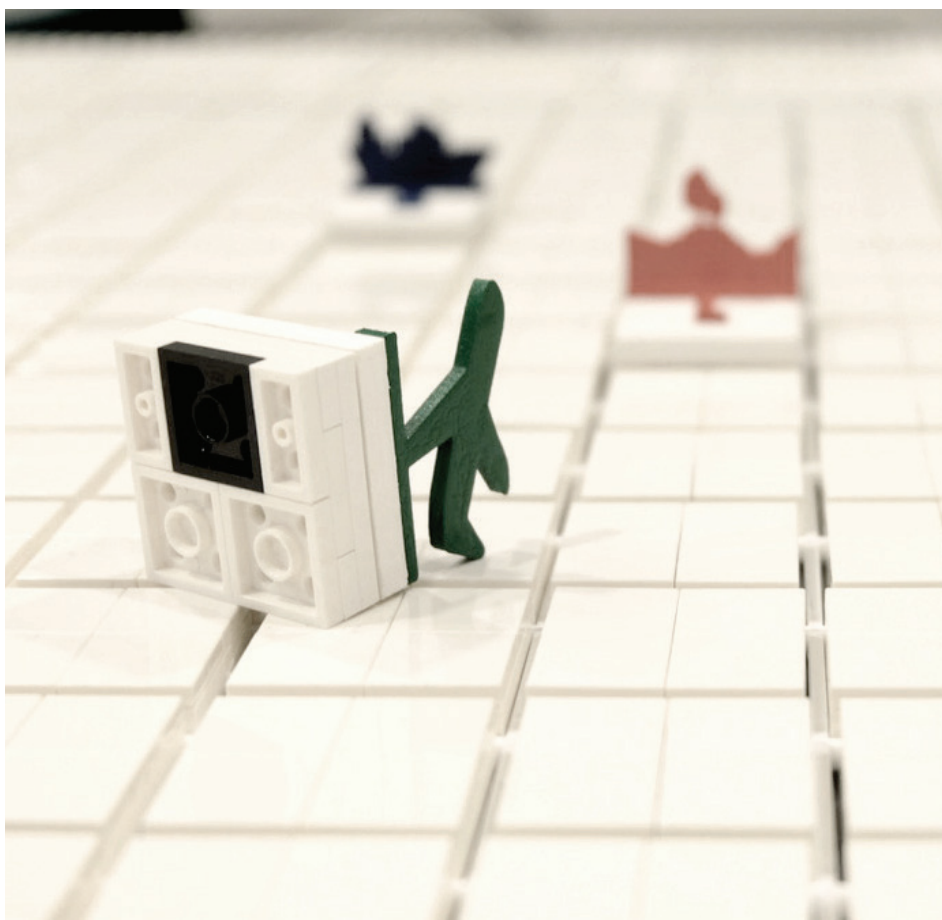
One display shows the overall collision numbers and collisions between separate agent species (A). The other display (B) shows a generated vector field in the area depending on level 2 agent inputs. Both displays support the CityScope Lapland table and provide a evidence-based overview of the impact the user's decisions made in the built environment.

Figure 37. Diagram presenting the scanning process of the LEGO® copyright symbol modules..



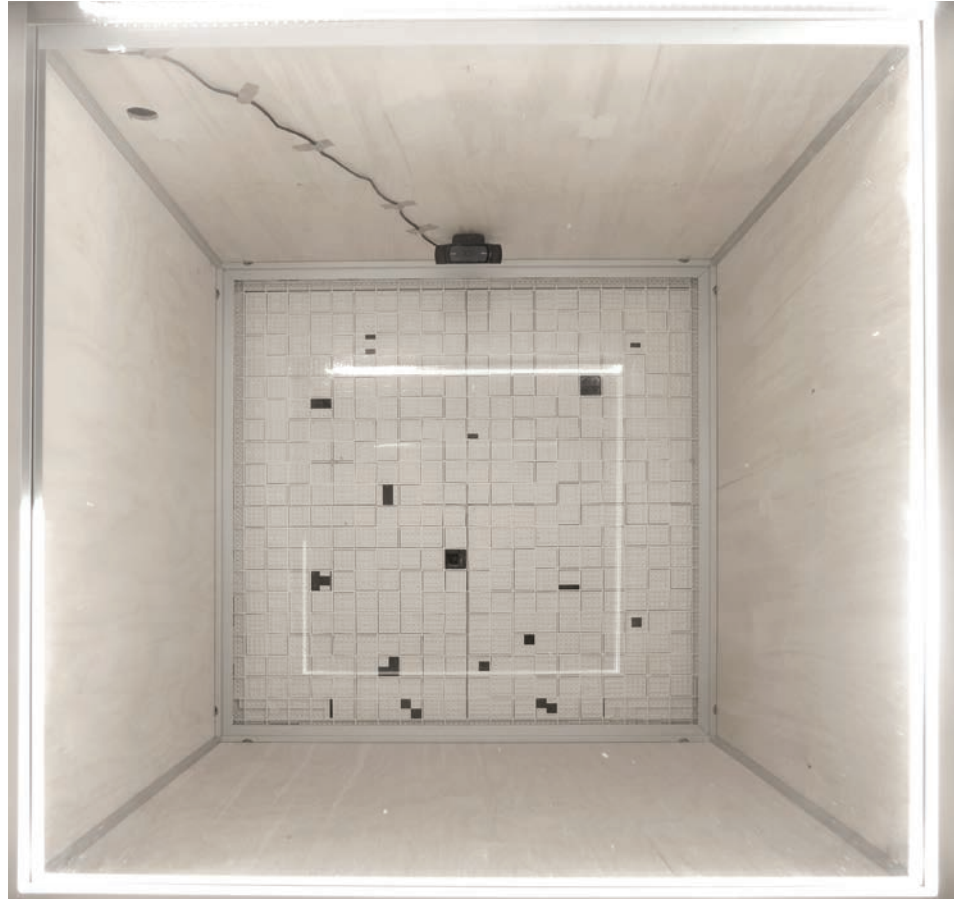


◀ *Figure 38. Photography showing the interaction process with the LEGO® modules when the simulation is running*



◀ *Figure 39. Photography showing LEGO® modules and their pattern tags.*

►  
*Figure 40. Photography showing mirrored web camera view inside the CityScope Lapland table.*



►  
*Figure 41. Photography showing a close look of the projected simulation model on the table.*



# Chapter 9

## *Reflections*

*The chapter has shown that the combination of tangible objects with abstract digital visualisation allows to translate computationally and conceptually complex models into a tangible format accessible for everyone. This translation allows multiple stakeholders to test more ideas within the same medium.*

*Furthermore, multiple displays help to solve a well-known problem of visualisation readability. Using separate displays and arranging them according to the most suitable and readable format can improve the user's reasoning for decisions.*

*Finally, the facilitation of existing university resources allowed to dedicate more time to developing the simulation model itself.*

# Chapter 10

## *Intro*

*The final chapter summarises the main findings of this master thesis, covering its multiple aspects: on-going Arctic transformations, the role of simulation models, the potential of Systems Thinking and patterns in planning and design tasks and the use of a tangible user interfaces as a medium for a discussion.*

*It reflects and evaluates the working process, specific and general challenges, and limitations encountered in the research and application parts. The chapter identifies the contribution to the presented thesis' problem, as well as discusses the presented decision support tool in relation to a broader field of planning and computational design methodologies.*

*The chapter is finished with a conclusion, pointing out the most important discoveries and outcomes, and proposes several outlooks for further project development steps.*



## 10. Discussion, Conclusion & Outlooks

### 10.1. The dialogue of main findings

#### **The Arctic**

The current globally-driven local changes in the built environment demand planners and architects to see beyond the building site or neighbourhood block when designing future developments. They need to recognise the different drivers shaping it, relations it has with the local surroundings and the global context. Naturally, due to the complex nature, it becomes difficult to articulate and put in use the global-local relationship for planning purposes. The simulation model created in this master thesis attempts to address this design challenge by finding relationships between those drivers and translates it into a network of underlying but not easily visible patterns of interconnectedness.

The research results and the presented decision support tool for planning and design tasks aim to identify the role time and direction patterns have on spatial transformations in Finnish Lapland. At the same time, it is a generic methodology, suitable for investigations in various scales, locations and systems. Observations from Chapter 2 about the Arctic spatial narratives confirm that similar controversial and complex projects have occurred and will occur across the region in the future.

As for the Arctic Ocean Railway case study, the thesis proposes better-informed strategies on how the project could be assessed using time and direction patterns of relevant agents. The analysed reports from the Finnish and Norwegian transport agencies (Finnish Transport Agency, 2018; Norconsult, 2018) give the general image of the project's role in the global and national context (see Chapter 3). However, there is little attention to the railway project's impact over time. The discussed impact of its directionality in the region does not represent its internal processes as a transportation corridor. The thesis attempts to address this knowledge gap through Systems Thinking and dynamic patterns.

The transition from a descriptive representation of the Arctic spatial narratives and the Arctic Ocean Railway project in Chapter 2 and 3 to a pattern-driven representation in Chapter 5 supports the initial statement that the case study is a highly complex and dynamic system. It consists of multiple dynamic subsystems, like reindeer herding, tourism or shipping. There exist stocks of resources and different populations, drivers like global and local demands, and feedback loops, e.g. an increasing annual temperature provokes permafrost thaw.

#### **Simulation-Model-Set-up**

In the context of the Arctic system, time and direction are relevant variables as they can be found in all selected spatial narratives. The manipulation of both variables in a model potentially improves the understanding

of the relevant dynamic behaviours that otherwise can be hard to perceive. Such insights can be used to transcribe and visualise interconnectedness between different agent groups over time and to support the information-based planning and design decisions. This approach is well articulated by Keith VanDerSys, who uses modelling to reveal changes in systems where patterns represent processes that have a physical impact (Cantrell & Mekies, 2018). An example of such an approach in one of his projects is presented in Chapter 4, where digital "kites" were used to visualise wind flows and conceptualise the ecological and social formations by displaying, otherwise invisible, information.

The results from the generic experiments with the designed simulation model (see Chapter 8) have shown several ways to evaluate spatial scenarios by using simulation outputs: collision maps and direction vector maps. Running the simulation multiple times and observing pattern reoccurrences, as well as, carrying out several different experiments increases the user's design intuition about the correlation between variable changes and results.

The designed dynamic collision map helps to detect moments and locations when agents form colliding situations. It can be instrumental in investigating the collisions' change and distribution over time. In such a way, times and locations with least collisions can be found and used to achieve best design solutions, e.g. the placement of a railway route and setting its frequency. Another way to use the collision maps in planning and urban design context is by communicating and familiarizing stakeholders with the spatially and temporally complex nature of projects, like the Arctic Ocean Railway.

In the thesis, direction vector maps were used to assess existing agent movement paths and the effort of the agent to move along it. The observation allows checking where interventions could be done to mitigate conflicting situations in an existing situation. An alternative way to use the direction vector map is to assess locations suitability for new movement paths by placing agents and observing their movement based on least needed effort. Road network design is one of the examples where such output could support planners in the decision-making process.

Examples from Chapter 4 show the existing relevance of time and direction patterns. The mentioned projects used time and direction in the strategy to look at urgent spatial challenges and mitigate the impact of heatwaves in Australia or air pollution in Beijing.

The presented computational design method is expandable and could also work with a different number of narratives. However, the selection of the spatial narratives should be based on the problem that is meant to be addressed.

Furthermore, the model outputs are sensitive to scale. Therefore, data like topography slopes or roads need to be abstracted to a suitable level. For example, it was observed that when generating direction vector maps for the regional scale, including all small lakes and slopes create noise, that damages the readability and performance of the simulation.

Additionally, the visual pattern representation is established

through dynamic video clips or snapshot images of a running simulation. Such representation is an attempt to understand the Arctic system beyond two-dimensional representations like mapping.

Finally, the simulation model utility depends not on whether its driving scenarios are realistic, but on whether it responds to a realistic pattern of behaviour. Particularly for planners and designers, modelling skills, exercised in generic experiments, might help to process and develop a holistic approach, not to represent the world as it is, but to exercise new ways of seeing it. Therefore, it supports the statement that “Patterns — formal, material, or temporal recurrences — are essential for perception “ (M’Closkey & VanDerSys, 2017).

### **Combining spatial narratives and simulation models**

The use of simulation models as a decision support method for a broad range of stakeholders in Lapland represents an opportunity to combine quantitative and qualitative theories, i.e. change between observations and hypotheses, within the same framework (Crooks et al., 2017). It confirms the compatibility of different approaches and the ability to facilitate it within the same tool. Furthermore, it combines multiple groups of people. For the decision support tool (see Figure 42), presented in this thesis, to work and to be fruitful, involvement of stakeholders, experts from different fields and designers is necessary.

However, the model’s implementation is demanding. It requires critical thinking and a careful translation from agents’ behaviour into computational parameters, as well as, linking the causality of certain phenomena with specific agent behaviour or conditions.

While mapping is a well-established planning method, it does not convey the dynamic aspect of the built environment in real-time. Also, current planning challenges require an understanding of the correlations and relationships between different actors over time in a quantitative fashion (Cantrell & Mekies, 2018). The proposed model incorporates the time aspect in its analysis and representation, thereby overcoming the existing issue with mapping, i.e. its static representation.

Furthermore, together with the mentioned simulation and modelling examples, like SimTable, UrbanSim, Relational Urbanism Models and Cityscope demos, the proposed model presents a workflow that constitutes a new approach to planning, decision-making, development strategies by non-experts and dialogue between the designers, the experts and the stakeholders (Alonso et al., 2018; Grignard et al., 2016, 2018; Noyman et al., 2017).

Finally, Chapter 6 briefly covered multiple modelling styles, like consolidative and exploratory, that have varying characteristics and results. The consolidative style creates more accurate and focused results but does not optimally suit the goal of the model needed for this thesis’ work. Meanwhile, exploratory modelling style fulfilled the expectations and objectives by defining salient characteristics and supporting the debate over particular problems (Bankes, 1993; Batty, 2013). Since different modelling styles

▼  
*Figure 42. Diagram showing the use of the designed decision support tool CityScope Lapland in planning and design tasks.*



can drastically influence the outcome, it is crucial to choose the most suitable to a specific task and problem.

### **Systems & Patterns**

Different spatial narratives in the Arctic and strategies to support them have unique concepts and ideas. In order to combine them, a more flexible and generic theory for planning and design is required. Systems Thinking can accommodate multiple different concepts and ideas because it is a generic theory and its framework is independent from the domain (Batty, 2013).

A transformation of separated spatial narratives into interconnected patterns only very generally addresses Saskia Sassen's idea of underlying dynamics. She states that: "[...] beneath the country specifics of diverse global crises lie emergent systemic trends shape by very basic dynamics." and that "[...] other dynamics are at work as well, dynamics that cut across these familiar and well-established conceptual/historical boundaries" (Sassen, 2014). Multiple spatial narratives were combined in this thesis, as an attempt to merge, otherwise often discrete, categories of phenomena.

Furthermore, this thesis supports the statement by Donella H. Meadows that "[...] in the end, everything is one system" (2008). The boundary of a system is subjective and depends on the one who defines it. This idea is visible in the thesis through the combination of different spatial narratives in one simulation model. Therefore, it should be kept in mind that connected parts might belong to different systems, even if it is just because of the imaginary boundaries that divide them.

This thesis' work also demonstrated how using Systems Thinking could address another challenge — a "high value" problem — introduced by computer scientist Chris Leckie. He states that "[...]the access to the vast amount of data demands a high level of critical thinking, forcing to 'pick out the interesting or unusual events that are worth exploring and then filter them down to high-value problems'" (Leckie, 2013). By selecting relevant patterns and attributes, it allows the designer to focus on underlying features, rather than trying to accommodate all available information.

### **Use of a tangible user interface**

The generic CityScope setup aims to visualise the complex urban data on a physical table, allowing real-time interaction and supporting planners with a dynamic, iterative and evidence-based process (Alonso et al., 2018). The created CityScope Lapland model accommodates these features in the Finnish Lapland context.

In the context of this thesis, the table setting allows condensing information about a complex system. It works as a medium for discussion and intensified knowledge exchange on a fixed-sized physical table surface even when talking about large-scale projects, like the Arctic Ocean Railway.

Generally, the combination of tangible objects, like LEGO® mod-



ules, together with an abstract digital visualisation allows to translate computationally and conceptually complex models into a tangible format for everyone. It further allows community members, local authorities or design professionals to test more ideas faster and receive real-time feedback.

What was observed in one of the interactive sessions is that since the simulation is running all the time, specific actions cannot be repeated without reloading the model. Making time steps relative and allowing stakeholders to move backwards and forwards in the timeline, would provide and additional ease on the interaction when wanting to repeat specific scenarios.

Finally, the CityScope Lapland attempts to question the facilitation and the role of a physical table in the planning discipline. Table, as a medium for knowledge exchange and discussion, finds references from popular culture and filmmaking, where every household's dinner table facilitates family discussions, to historical paintings portraying generals planning further battle actions. This image is alive in the collective imagination and finds its active roles as a facilitator of discussion.

## 10.2. Challenges

The challenges of the thesis' work were identified in the following areas: the representation and pattern visualisation possibilities in the planning and design tools, the model extent and different levels of abstraction, assessment of different spatial narratives and availability of programming skills.

Commonly, time- and direction data are not easily integrated into planning and design processes. This is because traditional spatial analysis tools do typically not include time and direction or its representation methods are not able to display these aspects most beneficially in order to gain further planning specific knowledge.

Moreover, patterns in systems are not easily visible. Therefore, a suitable visualisation is crucial in order to benefit from it. The ability to see patterns in complex systems might help to draw a more apparent connection between the elements in feedback loops.

The visual representation of information involves a multitude of theoretical principles, both analytical and aesthetical. It must have a representation suitable to the scale and the topic that clearly illustrates the system's behaviour and dynamics while excluding elements that might distort the results or disorient the observer. The designer should critically evaluate the presented material in order to prevent misleading communication. For example, time patterns should be represented in a way so that both, long- or short-term changes, are still visible in real-time in one or another way. Failure to do so can lead some stakeholders to reject the results altogether since no change is visible. Hence, special attention was given to the choice of data, as well as, the presentation method.

The choice of the abstraction level for the system itself, the system boundary and data can result in too high information reduction and can lead to an inaccurate system representation (Meadows, 2008). Fur-

thermore, the abstraction needs to be consistent throughout datasets and behaviours. One challenge experienced while designing the model, is the time scale for different agents. While the mine agents' lifespan cycle takes years to change its behaviour, train agents' schedule with the corresponding behaviour can take only minutes. The combination of such different time cycles is challenging to represent in one model.

The presented methodology illustrates well that the concept of spatial narratives is suitable to incorporate into the proposed model design, but it also raises a question of how to assess different narratives. For example, further investigation is needed to investigate direction strength values for different agents, like mines or airports and its change over time.

Finally, the CityScope Lapland table intends to be easy-to-implement and use, but the model still requires a fair level of modelling and programming knowledge.

### **10.3. Limitations**

The proposed planning and design decision support tool has some limitations in its current version. However, many of them are model-specific and could be solved with further development.

First, the final output does not show precise results due to the chosen scale but instead gives a speculation of a general situation.

Second, the reliability of the results is impacted by the input data quality and its translation into patterns. Building an accurate model requires the involvement of a broad range of experts from different fields to synthesize chosen spatial narratives into specific patterns, which in some cases might become an obstacle.

Third, the created computational simulation model has a defined simulation step length, i.e. which time period one step of the model simulates. Currently, this length is set to one minute, since this time is the smallest time step for the agent to execute an action. Therefore, the implemented model is, at the moment, more suitable to observe daily occurring patterns rather than long-term patterns.

Finally, computation power is a well-known limitation. In the case of the implemented model, there exists a limit on how many agents can be simulated smoothly (approximately 2000-3000).

Furthermore, while the idea itself might not have conceptual limitations, its practical implementation has limitations, due to the nature of modelling possibilities or the used simulation platforms.

### **10.4. Contribution**

No decision-support tool currently addresses and quantifies the agents' direct impact on the Arctic urban development or the relations of time and direction patterns among agents. This work is a contribution to the construction of such a tool. The project provides a methodology to visualize the information that can otherwise not be expressed and allows users to efficiently exercise judgment for different decisions in the project, rather

than proposing a totalizing solution.

The proposed design has multiple sides regarding its users: it can support professionals' and non-experts' decision-making processes in different ways. Designing the simulation model and generating its outputs might be more useful for the professionals in their planning and design tasks. Meanwhile, the CityScope Lapland table is more relevant for non-expert stakeholders because it stimulates direct communication through the easy-to-use interface. For the planners, such setup allows to trace back the decisions done by stakeholders that eventually form the boundaries of future planning and urban design tasks.

The shown results make time and direction patterns an additional support to other planning methods, providing a wider variety for spatial analysis with particular suitability for complex systems.

Finally, this project also attempts to return to the table as a discussion tool, that might seem to be neglected, but now makes its way back through multiple different projects from collaborative practices, academia and workshop culture.

## **10.5. Conclusion**

The thesis aims to explore and identify the role and potentials of dynamic time and direction patterns in regional planning and design tasks. Based on the done background research, existing examples, and simulation model outputs, it can be concluded that time and direction patterns have the potential for addressing large-scale regional planning and design challenges and can be instrumental in supporting decision-making. Multiple arguments support this conclusion.

First, in the context of the Arctic system, time and direction are relevant variables as they can be found in all selected spatial narratives. Therefore, they can be used to cut across scales, time and phenomena. The proposed decision support tool design is scalable and can be facilitated for a range of different projects in the region. Second, generated simulation model outputs allow to assess changing spatial conditions: projects can be evaluated over time with dynamic collision maps or flow of dynamic agents in space can be estimated with direction vector maps.

Furthermore, when dealing with systems, as complex as the Arctic region, planners are forced to filter down a vast amount of data to an underlying structure in order to address emerging planning challenges. It is essential to exercise a holistic approach to complex urban problems. However, current planning tools make it difficult to put such a complex nature of projects in use.

Systems Thinking and dynamic patterns, used in this thesis as a theoretical framework and methodology, has the capacity to abstract information about the different Arctic spatial narratives and move from a descriptive representation to a pattern-driven one. Patterns might be essential factors to describe spatial transformations. Therefore, the discovered patterns in various phenomena can become the material itself, that shapes it (Cantrell & Mekies, 2018).

Furthermore, the use of a tangible user interface - CityScope Lapland - combines quantitative and qualitative features in the planning process by showing the interaction between different agents in the simulation model, allowing to interact with it and test different assumptions. It provides a new basis for discussion, where through observing fast and slow impacts of time and direction patterns more informed boundaries for future planning projects can be drawn.

Finally, the proposed decision support tool attempts to involve multiple groups of people, like stakeholders, experts and planners or architects. It allows planners to understand better and track the spatial decisions done long before they join the project. It can be particularly valuable for the designer as it helps to understand the forces shaping boundaries of future projects. Furthermore, the use of CityScope Lapland by stakeholders from different fields can help to incorporate design thinking in decision-making processes early on and allow to familiarize with the complex nature of the project.

The designed decision support tool for planning and design tasks is developed to fit the master thesis' scope. However, already now multiple ways to proceed with this work are clear. Some of the potential improvements and following steps that could be made and would contribute to further development of the methodology of this decision support tool are described below.

## 10.6. Outlooks

### *Outlook 1: Implementation into the participatory process*

The proposed setup should be used in a real-life workshop, where various stakeholders could test different scenarios regarding a relevant problem. Observation of participants' behaviour, interaction with the tool, occurring errors and defects in the model, would provide valuable feedback. This feedback could be used for potential improvements for the interactivity with the table.

Allowing professionals, that designed the setup, and the stakeholders, that use it, to communicate and give feedback would inform about more readable representation modes.

### *Outlook 2:*

The simulation model, if used in different time steps (1 minute, hour, day, month or year), can produce a vast amount of data, potentially suitable for the use of machine learning algorithms. Such an algorithm could predict times and directions that are most conflicting for each agent species, empowering the designer to propose alternative scenarios.

Additional use of machine learning could be used in predicting the pattern tags clusters on the table. Since each of the LEGO® modules have a pattern tag on the bottom, interpreting the clustering and configuration of different patterns could provide suggestions for the urban decision-making.

ing process. It could be useful when seeking a particular goal or to overcome, often counterintuitive logic.

### *Outlook 3: Inclusion of interdisciplinary knowledge*

The concepts, like collision and direction vector maps, require further assessment and development to advance the use of the designed simulation model in regional planning tasks. Comparing the results with traditional planning analysis would be one of the ways to evaluate and calibrate the model and the methodology.

Furthermore, experts from individual fields should be involved in the process of providing and processing input data into patterns. This would improve model reliability and accuracy. For example, they could play an essential role in defining rules for counting collisions. Furthermore, more extended periods of model observations would provide a better understanding of various scenarios in the long term.

Currently, the direction vector map displays a “soft” vector field, i.e. it arranges vectors in a gradient manner which blurs case-specific situations. To create a more detailed direction map, principles how to assign vectors in situations where elements with isolating directions occur, e.g. bridges, tunnels, railway tracks or highways, need to be further developed. In a smaller scale, these specific situations often result in different landscape conditions than presented in the model.

Finally, it is already visible that the model holds more strategies to evaluate spatial situations that have not been covered in this thesis. The spectrum of such strategies could be assessed, as well.



# Aknowledgement

First, and foremost, I would like to thank my thesis supervisor prof. Pia Fricker for guidance throughout the process. Her ability to empower and boost my motivation and at the same time to challenge and push beyond my limits was fundamental for this thesis to come to life.

I would also like to thank Aalto University PhD. student Kane Borg for technical support and patience. Gratitude should also be expressed to Sanna Iltanen, coordinating CityScience Lab, for helping with practical matters of facilitating the CityScope setup. Easy communication, practical and technical support contributed significantly to the smooth development and creative process of this work. Furthermore, ADS research group meetings opened me to interesting concepts and ideas that indirectly affected the progress of this thesis.

Separate gratitude should be expressed to fellow students Babak, Jenna and Ye without whose passionate inputs and opinions I would not have taken many things into account.

An additional acknowledgement should be given to TU Berlin Architecture department chair CHORA, prof. Raoul Bunschoten and the tutors. The studio course ‘Supply Chain Urbanism’ taken during my exchange semester there, triggered my interest in global urban systems and ambition to stress its boundaries through speculative projects.

Finally, the great thank should be dedicated to my family and partner for believing in my ideas sometimes more than I do and for continuous encouragement and support throughout the master studies. Without their support, this would not have been possible. Thank you.

Author,

Ayda Grisiute

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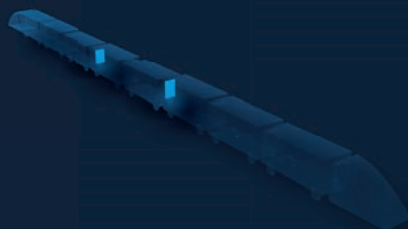
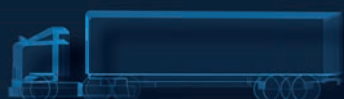
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