THE AGENCY AND GEOGRAPHY OF SOCIO-TECHNICAL TRANSITIONS:

THE CASE OF URBAN TRANSPORT INNOVATIONS

DOCTORAL THESIS IN ECONOMIC GEOGRAPHY

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English Abstract

The objective of this cumulative thesis is to gain deeper insights into the interplay of agency and structure through the empirical example of emerging technologies in the context of Industry 4.0. To achieve this goal, it enriches the theoretical background from evolutionary economic geography with insights from transition studies and management studies. Empirically, the analysis focuses on novelty creation toward intelligent transport systems in an urban environment. This encompasses software solutions such as big data platforms for traffic management, the Internet of Things to create a network of various objects and subjects within the city, or the development of autonomous vehicles. This thesis formulates four overarching research purposes: (1) comprehending socio-technical transitions during Industry 4.0 from an agency-based perspective; (2) understanding how agency facilitates or hinders innovation development; (3) identifying the impact of multi-scalar and cross-sectoral relations; and (4) integrating different theoretical approaches to gain a holistic understanding of the empirical domain. The thesis adopts a qualitative research design with a philosophical grounding in critical realism, drawing on semi-structured expert interviews, literature reviews, and document and network analysis. Moreover, this thesis is interdisciplinary in its practical and methodological execution, as the author was part of applied research projects with close ties to the technical development of the respective technologies. The main contribution of this thesis rests on four distinct research papers. A systematic literature review sets the conceptual basis for the analysis, identifying future research avenues based on the existing research body. The first case study analyzes the development of an app-based solution for managing urban logistics in Barcelona from a multi-level perspective. The other two case studies investigate the evolution of advanced air mobility in Germany and the city of Hamburg, emphasizing a differentiated understanding of change agency and the consideration of entrepreneurial ecosystems. Through the discussion, it becomes evident that there is a current lack of research on the topic of Industry 4.0 in economic geography, with weak connections to neighboring disciplines addressing spatial implications of associated challenges and developments. Moreover, the academic debate is highly conceptual with only a few qualitative insights. The thesis emphasizes the need for a better understanding of institutional factors. Persistent institutions, both formal and informal, have a decisive influence on the socio-technical transition in all case studies. These include legal frameworks within an existing socio-technical regime, the routines of users, and the social acceptance of technologies. As a result, developers must transfer innovations to other spatial contexts with diverse institutional environments and bridge numerous sectoral knowledge bases. Furthermore, the thesis questions the rather static understanding of powerful key actors in the conceptual literature with a special emphasis on their institutional embeddedness, regional preconditions, and the interplay of ecosystems and regional innovation systems. A multi-theoretical approach not only contributes to the academic debate on socio-technical transitions but also proves to be essential for an interpretation of a specific use case.

Deutsche Zusammenfassung

Das Ziel dieser kumulativen Arbeit ist es, ein tieferes Verständnis für das Zusammenspiel von Agency und strukturellen Eigenschaften durch das empirische Beispiel neuer Technologien im Kontext von Industrie 4.0 zu gewinnen. Zu diesem Zweck nutzt die Arbeit Erkenntnisse aus der evolutionären Wirtschaftsgeographie, den Transition Studies und Managementstudien. Konkret konzentriert sich die Arbeit auf die Innovationsentwicklung im Bereich intelligenter Transportsysteme in einer städtischen Umgebung. Diese umfasst Software-Lösungen wie Big-Data-Plattformen für das Verkehrsmanagement, Internet-of-Things-Anwendungen zur Vernetzung verschiedener Objekte und Subjekte innerhalb einer Stadt oder die Entwicklung autonomer Fahrzeuge. Um dieses Forschungsziel zu erreichen, formuliert die Thesis vier übergreifende Forschungsziele. Dazu gehören: (1) das Verständnis von sozio-technischen Übergängen im Zuge der Industrie 4.0 aus einer handlungsbasierten Perspektive; (2) das Verständnis davon, wie Agency die Entwicklung von Innovationen fördert oder hemmt; (3) die Identifikation der Auswirkungen von multi-skalaren und sektorenübergreifenden Beziehungen; und (4) die Integration unterschiedlicher theoretischer Ansätze zur Erlangung eines umfassenden Verständnisses der Empirie. Die Arbeit verfolgt einen qualitativen Forschungsansatz mit einer philosophischen Verankerung im Critical Realism und nutzt semi-strukturierte Experteninterviews, Literaturreviews sowie Dokumenten- und Netzwerkanalysen. In methodischer Hinsicht ist diese Arbeit ebenfalls interdisziplinär und praktisch orientiert, da durch die Einbettung in angewandte Forschungsprojekte ein enger Kontakt zur technologischen Entwicklung der jeweiligen Fallbeispiele bestand. Der Hauptbeitrag der Arbeit beruht auf vier eigenständigen Forschungsartikeln. Eine systematische Literaturübersicht legt die konzeptionelle Grundlage für die Analyse dar und identifiziert zukünftige Forschungsansätze für die Verbindung von Industrie 4.0 und der Wirtschaftsgeographie. Die erste Fallstudie analysiert die Entwicklung einer App-basierten Lösung zur Verwaltung von städtischer Logistik in Barcelona aus einer Multi-Level Perspektive. Die anderen beiden Fallstudien untersuchen die Entwicklung autonomer Luftmobilität in Deutschland und der Stadt Hamburg und betonen ein differenziertes Verständnis von Agency und die Berücksichtigung von unternehmerischen Ökosystemen. In der Schlussfolgerung wird deutlich, dass es derzeit einen Mangel an Forschung zum Thema Industrie 4.0 in der Wirtschaftsgeographie gibt, mit schwachen Verbindungen zu benachbarten Disziplinen, die sich mit den räumlichen Implikationen der damit verbundenen Herausforderungen und Entwicklungen befassen. Zudem ist die akademische Debatte stark konzeptionell geprägt und bietet nur wenige qualitativ-empirische Eindrücke. Die Arbeit betont die Notwendigkeit eines besseren Verständnisses der institutionellen Faktoren. Formelle und informelle Institutionen haben einen signifikanten Einfluss auf die sozio-technische Übergange in allen Fallstudien. Dazu gehören rechtliche Rahmenbedingungen innerhalb eines bestehenden sozio-technischen Regimes sowie die Routinen der Nutzerinnen und Nutzer und die gesellschaftliche Akzeptanz von Technologien. Als Konsequenz müssen Entwicklerinnen und Entwickler ihre Innovationen in andere räumliche Kontexte mit eigenen

institutionellen Umgebungen übertragen und unterschiedliche sektorale Wissensbasen verbinden. Darüber hinaus hinterfragt die Arbeit das statische Verständnis von Schlüsselakteuren in der konzeptionellen Literatur und forciert die Auseinandersetzung mit der institutionellen Einbettung, regionalen Voraussetzungen, sowie dem Zusammenspiel von Ökosystemen und regionalen Innovationsystemen. Ein multi-theoretischer Ansatz ist somit nicht nur essentiell für die akademische Debatte über sozio-technische Übergänge, sondern auch wesentlich für die Interpretation eines spezifischen Anwendungsfalls.

Declaration

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person nor material that has been accepted for the award of any other degree or diploma of the university or other institute of higher learning, except where due acknowledgment has been made in the text.

This thesis has been prepared subject to the Rules of Good Scientific Practice of the German Research Foundation. I declare that no academic degree has been withdrawn from me.

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Introduction and synthesis of the cumulative thesis

The agency and geography of socio-technical transitions: the case of urban transport innovations

1. Introduction

The emergence of Industry 4.0, as the main synonym for the technological developments of the fourth industrial revolution, has sparked numerous debates regarding the potential structural changes and societal implications associated with these innovation processes (Zuboff, 1988). The introduction of key technologies such as artificial intelligence and the Internet of Things (IoT) has yielded significant advancements. The connection between objects and/or subjects through algorithmizing leads to novel digital platforms for networked industrial production. For instance, scholars debate the impact of this transformation on the labor market or the reshoring of existing global value chains (De Backer et al., 2016; Frey & Osborne, 2017). One area in which these emerging technologies have seen increasing application is the transportation sector. Innovations in routing, intelligent transport systems, autonomous vehicles, and cybersecurity raise great expectations for improving urban traffic, addressing issues such as high ecological emissions or overloading of existing infrastructure, and providing transparent traffic monitoring for municipalities. Furthermore, these advancements have led to the creation of fundamentally new types of vehicles, such as advanced air mobility (AAM), that fulfill potential use cases for both passenger and cargo transport. Despite a multitude of debates and various scenarios surrounding Industry 4.0, empirical studies to date provide limited insight into the formation of development paths (Fraske, 2022). The integration of digital innovations into existing socio-technical systems requires overcoming a variety of barriers, including testing new technologies in different societal and physical surroundings, while accounting for persistent formal (e.g., legal frameworks) and informal institutions (e.g., work routines). The challenges for entrepreneurship are closely linked to the decisions of policymakers at the local, national, and European levels, as well as the appropriate participatory embedding of civil society. The implementation of digital innovations must be done with careful consideration of these aspects to successfully enter existing socio-technical systems.

Over the past few years, the field of economic geography has placed an increasing emphasis on understanding the influence of digitalization on space and the discipline itself (Ash et al., 2018; Haefner & Sternberg, 2020). Spatial implications of this phenomenon include the diversification of industries on a regional level due to emerging technologies (Boschma et al., 2018), as well as the geography of innovations and approaches to explaining specific path developments (De Propris & Bailey, 2021). The paradigm of evolutionary economic geography (EEG) is particularly concerned with explaining the evolution of industries across space and time. However, a critical limitation exists in terms of properly

accounting for human agency and the empirical explanation of causal relationships between individual decisions and structural change. Human agency refers to the capability of individuals to take action with intention and create observable outcomes in the world around them (Gregory et al., 2011). The intended and unintended outcomes of purposeful and meaningful actions by human actors can thus have a decisive influence on spatial and structural phenomena (Grillitsch & Sotarauta, 2020). Therefore, economic geographers should be highly interested in engaging with the topic of Industry 4.0 from a multi-scalar perspective, as the research field poses great potential for empirical endeavors on the spatial implications of this transformation and associated socio-technical processes.

This thesis draws on three theoretical research strands that aim at better understanding socio-technical development and the transferability of innovations from small niches to broad utilization:

(1) An *evolutionary and path development* perspective that considers the evolutionary characteristics of the developments and emphasizes the spatiotemporal dimensions of these processes (Grillitsch et al., 2022). This requires a deeper understanding of how to theoretically frame human agency from a geographic perspective. The trinity of change agency proposed by Grillitsch and Sotarauta (2020) requires differentiated skills and competencies, such as innovative, institutional, and place-based dimensions of change. Additionally, the literature is concerned with the distinction between path dependence and path creation (Garud et al., 2010; Sotarauta & Grillitsch, 2023) as well as the diversification of regional industries, thus highlighting the importance of cross-sectoral influences.

(2) A *socio-technical transition* perspective refers to the growing interdisciplinary research body on transition studies and established concepts like the multi-level perspective. The main conceptualization of niches, socio-technical regimes, and landscapes has become a common narrative within innovation studies (Geels, 2002). The literature emphasizes that new solutions must overcome existing preconditions in the socio-technical regime, such as formal institutions or physical infrastructures, or adapt them for the utilization of emerging technologies. The literature also draws on the idea of windows of opportunity (Tyre & Orlikowski, 1994) and how actors may identify the right place and time to implement a new idea within an existing regime. Despite the greater engagement of economic geographers with this theoretical strand (Binz et al., 2020; Murphy, 2015), transition studies have yet to overcome a "naïve conceptualization of space, scale, and power" (Truffer & Coenen, 2012, p. 15).

(3) An *entrepreneurial ecosystem* perspective accentuates the role of key actors (or "orchestrators" in the theoretical terminology) and entrepreneurship to accelerate innovation development and strengthen bottom-up processes (Spigel & Harrison, 2018). To aim at a collective system-level output, the literature stresses the importance of creating legitimacy for emerging technologies, such as social acceptance or the integration of new legal frameworks (Thomas & Ritala, 2022). Hence, narratives and discourses surrounding socio-technical developments can play a vital role in the evaluation of new solutions.

The goal of this thesis is to gain deeper insights into the interdependencies between human agency and structural change with an empirical focus on Industry 4.0 and, more specifically, the socio-technical integration of urban transport innovations. The main contribution lies in the empirical refinement of various analytical frameworks to get a deeper and more holistic understanding of the interdependencies and causalities of these innovation processes. This cumulative thesis consists of four distinct research papers. The first paper provides a systematic literature review on the current state of research on Industry 4.0 in economic geography and discusses future research avenues. The first case study investigates the development of an IoT solution to regulate urban logistics in Barcelona, while the other two case studies focus on the emergence and integration of AAM in Germany and the city of Hamburg. While all four papers address specific and differentiated questions and concepts, this cumulative thesis formulates four research questions that serve as a guideline for the overall analytical contribution. The research questions are as follows:

RQ1: *How can an agency-based perspective in evolutionary economic geography enrich our understanding of the socio-technical transitions emerging during Industry 4.0?*

The first research question acts as an overlaying research question that mirrors the original intent of this cumulative thesis. Hence, the question aims at understanding the current role of human agency in EEG and identifying research gaps. The goal is to gain a deeper understanding of the current empirical engagement of geographers with research on Industry 4.0. The research question primarily resembles the theoretical embedding of this thesis as well as in the systematic literature review on economic geography and Industry 4.0 (Paper 1). For the empirical endeavor, the question is further disentangled into three follow-up questions:

RQ2: *To what extent does human agency enforce or hinder the transferability of an innovation?*

This research question primarily aims at understanding the challenges and interdependencies between human agency and structural change. Special attention is drawn to the skills, decision-making, and institutional embedding that actors engaging with the socio-technical integration of emerging technologies must consider or provide for a successful transition. This entails a reflection of the structural barriers and regional preconditions that the actors must address and how these spatial implications may act as a catalyst or obstacle for the innovation process.

RQ3: *To what extent can multi-scalar and cross-sectoral interactions affect the success of an innovation?*

Building up on this geographic dimension of innovation development, I further accentuate the multi-scalar relations of these processes. This includes a reflection on the practical and discursive exchange between different actors across places and scales and how they use different regional preconditions to enhance their solutions. This aspect accounts especially for trans-local learning processes and how actors

overcome persistent institutional patterns. In this regard, I emphasize the cross-sectoral nature of Industry 4.0 development. As digital innovations must bridge existing and new emerging knowledge bases (such as between the logistics sector and artificial intelligence development) actors must understand the outcome of radical innovations and their impact on established structures and vice versa. This raises questions regarding the requirements of overcoming sectoral boundaries and how developers cope with the associated challenges during this process.

RQ4: *How can we combine different theoretical strands to develop a more holistic understanding of human agency in economic geography?*

Finally, I want to accentuate multiple theoretical avenues and conceptual approaches to working towards a holistic understanding of human agency and its spatial implications in the context of Industry 4.0. Hence, the case studies use various frameworks with different theoretical backgrounds to embrace different perspectives on this research topic. While all approaches have their distinct strengths and weaknesses, our empirical observation and interpretation of the reality are dependent on a comprehensive research design that does not fall short of interdisciplinary engagement and the different understanding of terminologies within the literature. The empirical testing and conceptual refinement of existing frameworks thus remain a key challenge for researchers.

The introduction and synthesis of the thesis are structured as follows: Chapter two outlines the underpinned philosophical embedding of critical realism and discusses the current debate of human agency in EEG with a special interest in the synthesis between different concepts, namely the trinity of change agency, transition studies, and entrepreneurial ecosystems. In chapter three, I provide an overview of my motivation and the background of this research as well as a contextualization of the empirical research field of urban transport innovations. Following up, chapter four presents the qualitative research design. Moreover, I outline the methodological approaches and applied research projects that I was part of. Chapter five summarizes the main findings of the individual papers and how they contribute to the objectives of this thesis. Subsequently, chapter six concludes by answering the research questions, identifying the limitations and future research avenues, as well as implying policy and practical implications of this research.

2. An evolutionary perspective on human agency

This chapter provides a holistic overview of the theoretical framework of this thesis. For this purpose, the philosophical embedding of this thesis is outlined and the agency term is operationalized and contextualized in the wider context of evolutionary theories. This discussion is followed by an outline of the theoretical concepts and conceptual frameworks that have been used in the empirical research. This chapter serves as an overview, a more elaborated and detailed perspective on the theories is part of the respective articles.

2.1 Critical realism as an underpinned philosophy

This thesis is positioned in the philosophical embedding and ontology of critical realism. Critical realism itself is not an actual theory of society, but rather a philosophy of science that tries to explain "what (good) science is and does (Gorski, 2013, p. 660)." The general assumption of critical realism lies in the idea that there is a reality beyond our ability to observe. Therefore, we need to develop processes to gain knowledge about these underlying structures and identify causal mechanisms within them (Farquhar, 2012; Mingers, 2004; Rühlemann & Jordan, 2021). Bhaskar (2013) distinguishes between three ontological domains that form the basic understanding of critical realism. The *reality* cannot be directly observed, though the structures and mechanisms can generate events. These events form the domain of the *actual* and can be perceived by humans. If these events become observed by humans, their *experiences* form the empirical domain. The philosophical approach clearly emphasizes the idea that actors and their perception of their observations in the real form stand in mutual relation to social structures. As Sayer (1999) summarizes, critical realism highlights that social phenomena are intrinsically meaningful and meaning must be perceived and understood and not measured or counted. Hence, there is always an interpretative and hermeneutic element in social science. Bridging these thoughts with the empirical focal point of this thesis, the emergence of innovations and their socio-technical integration is tied to the observation and experience of the involved actors and vice versa. A realist approach aims at the further development and refinement of theoretical frameworks by gaining new empirical insights and synthesizing existing literature (Pawson, 2002; Rycroft-Malone et al., 2012). Figure 1 illustrates the ontology of critical realism.

The question of why empirically oriented researchers should be concerned with and reflect upon the philosophical basis of their research has been raised by Gorski (2013). Geographers can benefit from adopting a critical realist perspective, which enables them to better understand the contextual grounding and causal mechanisms of their empirical observations. Or more precisely, to engage critically with the context-sensitivity during the process of re-theorezing (Gong & Hassink, 2020). As a result, economic geography has witnessed a growing interest in the philosophical underpinnings of critical realism in the context of theorizing literature (Gong & Hassink, 2020; Pratt, 1995; Sotarauta & Grillitsch, 2023; Yeung, 1997). From a realist perspective, causality derives from the power of social structures that influence the intentions of the individual actors that co-constitute them (Gorski, 2013). Hence, there is a clear ontological distinction between structure and agency (Sotarauta & Grillitsch, 2023). This is a fundamental aspect that revolves around the question of the extent to which social structures and processes are context-dependent or can be explained by law-seeking approaches (Sayer, 1989). Therefore, agency is understood as a bridging concept between structure and actors, rather than an opposite or counterpart of structure (Gorski, 2013). To advance theories in economic geography, it is essential to test concepts and theories in contemporary settings and new contexts (Gong & Hassink, 2020). Critical realism emphasizes a qualitative or mixed-method research design since it is better suited

to identify causal relations rather than regularities (Gong & Hassink, 2020; Yeung, 1997). In the process of theorizing, it is crucial to emphasize context-sensitivity. Social observation is the starting point for theory development, and empirical research can be utilized to construct more context-specific or process-sensitive concepts or theories. Once a pattern or a set of patterns is identified, researchers can test it in different contexts and under various conditions, allowing them to revise the theory where necessary (Gong & Hassink, 2020).

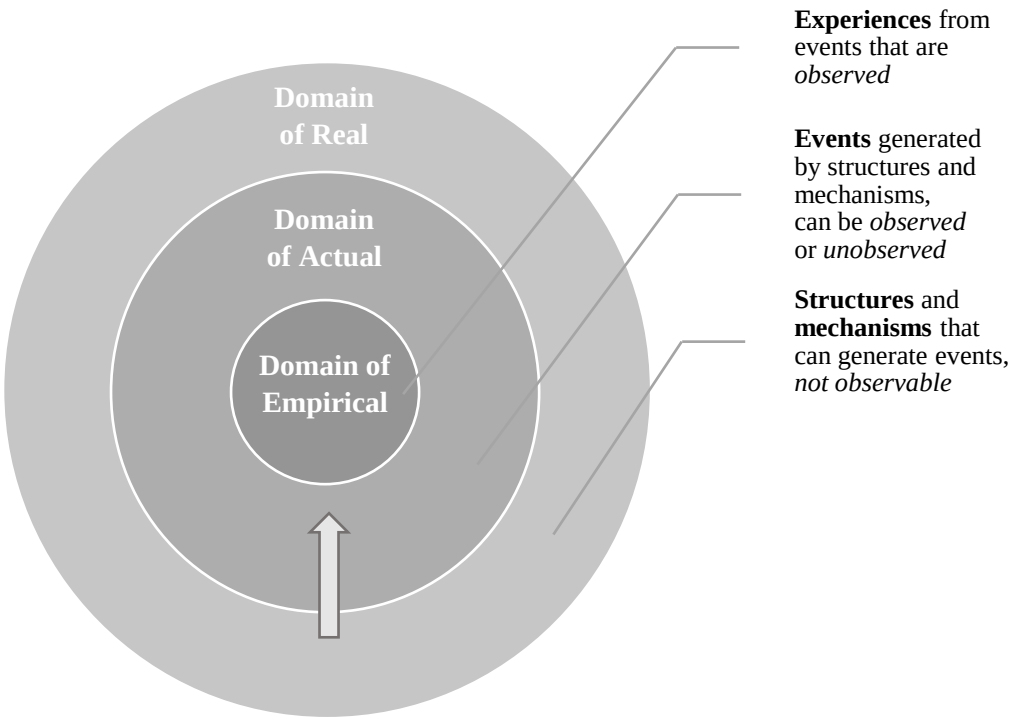

Figure 1: Critical realist ontology, based on Mingers, 2004.

Regarding this thesis, the aim is to evaluate the validity of existing theoretical frameworks in the context of Industry 4.0, which is characterized by emerging technologies. To this end, I will explain the initial social observation and problem definition of the respective technologies in each research paper before developing a suitable theory for application. Moreover, a systematic literature review will provide an overview of the causal relations discussed in the research field's literature. Ultimately, empirical feedback from different case studies will enable us to revise theories and enhance our understanding of Industry 4.0 processes.

2.2 Evolutionary economic geography and the role of agency

In the dictionary of human geography, human agency is defined as "the ability of people to act, usually regarded as emerging from consciously held intentions, and as resulting in observable effects in the human world" (Gregory et al., 2011, p. 347). The historic discussion of human agency within geography

dates back to old deterministic paradigms, where human agency was generally regarded as a result of structural preconditions (Peet, 1985). The discussion in which human geographers participated slowly opened for a more mutual understanding of structure and agency over the decades, influenced by overlaying discourses such as the decision-making of the homo oeconomicus (Barnes, 1988), structuration theory (Giddens, 1984), and the cultural turn within human geography (Barnett, 1998). A key contemporary aspect in the debate on the linkage between structural change and agency lies in the argument of to what extent agency impacts structure or whether actors themselves are constrained or even guided by structural preconditions in their actions (Gregory et al., 2011). This links to the general differentiation between reproductive agency on the one hand, which aims at maintaining a status quo; and transformative agency on the other hand, which aims at breaking with existing paradigms and establishing novelties in existing development paths (Coe & Jordhus-Lier, 2011).

EEG focuses on the question of how economic and regional development unfolds and differs in its spatial dimension. Unlike deterministic and random developments, evolutionary change assumes that future events are always dependent on past events (Nelson & Winter, 1977, 1982, 2002). EEG thus focuses analytically on "processes by which the economic landscape - the spatial organization of economic production, circulation, exchange, distribution, and consumption - is transformed from within over time" (Boschma & Martin, 2010, p. 6). Conceptually promising approaches focus on path dependency and path creation (Martin & Sunley, 2006) as well as innovation-related approaches such as relatedness (Boschma et al., 2012) and co-evolution (Gong & Hassink, 2019; Ter Wal & Boschma, 2011). These approaches aim to capture the reciprocity of technological innovation development and exogenous factors such as institutions in a region (Murmann & Homburg, 2001).

The role of agency and its relation to the structure is still considered a "blind spot" in economic geography by some authors (Grillitsch & Sotarauta, 2020). In recent years there has been a growing interest in new theoretical engaging with this matter by geographers. Among others, these include the longitudinal and spatiotemporal dimensions of change agency (Grillitsch et al., 2022; Jolly et al., 2020), multi-scalar perspectives on transition trajectories (Miörner & Binz, 2021), and spatial capabilities and agency for path creation in the context of Industry 4.0 (De Propris & Bailey, 2021).

Human agency from a modern understanding can thus be defined as intentional, purposeful, and meaningful actions. The consequences of these actions can be both intended and unintended (Grillitsch & Sotarauta, 2020). It closely evolves around two understandings of path development within economic geography: Path dependence and path creation. A path refers to a "temporal sequence of events, it is the course or direction in which, for example, a region or an industry in a region is moving (Sotarauta & Grillitsch, 2023, p. 87)." Path dependence assumes that paths are sensitive to early events of an overall historic event, based on contingent occurrences, and relatively deterministic casual patterns, defined as “inertia” (Mahoney, 2000). In contrast, path creation assumes that critical incidents are not given but

constructed by agents themselves and their perceptions and interpretations of their environment and key events in the past (Garud et al., 2010; Sotarauta & Grillitsch, 2023). Hence, a path creation perspective emphasizes a process-oriented understanding, that focuses on mico-level phenomena such as narratives of individual actors and how they perceive opportunities differently (Sotarauta & Grillitsch, 2023).

Grillitsch and Sotarauta (2020) propose the trinity of change agency as a conceptual framework to empirically engage with this research topic. They outline three theoretical strands of change agency: (1) *innovative entrepreneurship*, which aims at the discovery and exploitation of opportunities for value creation, and the willingness of entrepreneurs to create something new (Schumpeter, 1911); (2) *institutional entrepreneurship*, which is concerned with institutional change (Granovetter, 1984; Storper, 1997) that leads to the creation or transformation of formal and informal institutions that shape regional development; (3) *place-based leadership*, which emphasizes the mutual relationship between actors and the regional preconditions, such as efficient networking strategies or access to extra-regional knowledge bases (Isaksen & Trippl, 2017; Sotarauta, 2016). The concept of the trinity of change agency is further discussed and empirically applied in paper 3 of this cumulative thesis.

The spatiotemporal dimension of path development is reflected in the idea of opportunity spaces, which have become a common term in different strands of socio-technical research on innovation breakthroughs and regional development (Perez & Soete, 1988; Tyre & Orlikowski, 1994). In that sense, they are the bridge between the emergence of a novelty and its embeddedness within existing structural patterns. Grillitsch and Sotarauta (2020) distinguish between time-specific (e.g., knowledge, institutions, resources such as funding programs), region-specific (e.g., preconditions such as existing knowledge bases), and agent-specific (e.g., capabilities of individuals, such as the ability to enforce institutional change) parameters to outline and understand opportunity spaces empirically. The main assumption in this regard is that opportunity spaces are not being created unintentionally or as a random event, but they can be initiated, created, and maintained by actors themselves and are dependent on the decisions and expectations of key actors. A conceptually clear and empirically grounded understanding of agency within paradigms of economic geography is of high importance, especially for those with a naturally strong focus on regional development. Hence, the human agency needs a stronger position within established and new frameworks and theoretical debates within EEG.

2.3 Transition studies and the multi-level perspective

Just like the EEG paradigm, transition studies originate in the idea of evolutionary economics. The fundamental presumptions of socio-technical systems are connected to the theoretical discussion of sustainability transitions. They are especially concerned with the introduction of environmentally friendly technologies into society, and as a result, have close ties to environmental and climate research (Martin, 2012). Given that they offer one of the most prevalent conceptual frameworks with the multi-level perspective, political science and sociology are closely related to the theoretical discipline (Geels,

2002, 2011, 2014, 2020). The multi-level perspective developed into a well-known theory to study socio-technical transformations throughout the previous two decades. To assess a transition, it establishes three primary analytical levels (Geels & Schot, 2007): (1) the *socio-technical niches*, in which a few cooperating actors advance innovation. These "protective spaces" act as incubators outside the existing regime where emerging technologies can be invented, tested, and marketed outside the selection processes within the regime (Kemp et al., 1998; Smith et al., 2010); (2) the *socio-technical regime*, which constitutes a socio-technical fabric of various actors and practices and ensures certain connections and modes of action between a technology and societal space. The change within regimes can generally be described as incremental and path-dependent (Smith et al., 2010); (3) the *landscape developments* describe exogenous and superordinate change outside of niches and regimes that are usually continuous and slow. Examples include demographic change, social movements, changes within the political systems, or changes in cultural or scientific paradigms (Smith et al., 2010). These general analytical levels and terminologies have manifested as a common understanding in transition studies and beyond. Other notable theories within this field are transition management (Rotmans et al., 2001) and strategic niche management (Kemp et al., 1998). A geographic understanding of the multi-level perspective serves as the theoretical background for paper 2.

Recent years have brought a growing focus on the geography of transitions as an emerging research field, yet further case studies and theoretical rethinking are required (Coenen et al., 2012; Coenen & Truffer, 2012; Fastenrath & Braun, 2018; Hansen & Coenen, 2015; Truffer et al., 2015). Despite the growing body of research that takes agency as an important analytical element into consideration, certain shortcomings can be highlighted regarding evolutionary economics and its associated theoretical frameworks. Evolutionary theories frequently rely on a firm-centered perspective that ignores the relevance of exogenous impact and resources from non-economic actors (Hassink et al., 2019). Moreover, the geographic understanding of transition studies is often not meeting the requirements for a sufficient and comprehensive understanding of space (Binz et al., 2020). The first conceptual frameworks that try to combine insights from EEG and transition studies try to overcome these shortcomings. Boschma et al. (2018) create a framework that focuses on the role of regional diversification. They stress the importance of analyzing the unrelated variety of a region, as transition studies often fall short of providing a comprehensive understanding of regional specialization. Murphy (2015) focuses on a human geographical approach, in which he highlights the role of legitimization and confidence in niches and regimes and how they influence political decision-making. Although these promising frameworks offer a first step into a theoretical discussion of transitions from a geographical perspective, there is a lack of empirical studies that can locate and further develop them.

The geography of transitions is concerned with the extent to which spatial relationships can influence the success of socio-technical transitions and how paths can differ depending on their location (Hansen & Coenen, 2015; Köhler et al., 2019). Several spatial factors emphasize the importance of geography in

sustainability transitions, such as urban and regional visions and policies, informal localized institutions, natural resource endowments, industrial specialization, or local market formation (Hansen & Coenen, 2015). Geographic concepts, therefore, need a more practice-oriented perspective, that takes trans-local drivers and barriers of transition processes into consideration (Fastenrath & Braun, 2018). Despite the research becoming increasingly differentiated, there is still a strong research bias on typical green technologies and the research pays less attention to peripheral development processes (Binz & Truffer, 2017; Fuenfschilling & Binz, 2018). As the findings of this thesis highlight, the relevance and impact of digital transformation and digital innovations remain understudied as well and call for a necessary extension of the existing frameworks.

2.4 Entrepreneurial ecosystems

The theoretical origin of entrepreneurial ecosystems lies in management studies but has been adopted widely across a variety of disciplines in the past years. Ecosystems can be described as "organic constellations of organizational participants that collectively cocreate ecosystem-level outputs" (Autio & Thomas, 2021, p. 12). The interdisciplinary debate about ecosystems has also led to different understandings of what an ecosystem is and how these various notions can be distinguished conceptually. Entrepreneurial ecosystems are led by entrepreneurs themselves (Stam, 2015) and should encourage them to participate and take risks for funding or venture creation (Spigel, 2017). The core distinction of ecosystems in comparison to other concepts such as clusters or regional innovation systems lies in the *collective* and *voluntary* engagement of its participants to create a *system-level output*, such as the creation of new business models (Autio & Thomas, 2021). Therefore, the concept clearly emphasizes a bottom-up approach to innovation development. Moreover, the *heterogeneous participants* of an ecosystem fulfill different roles and are linked through certain *interdependencies*, such as spatial proximity (Autio & Thomas, 2021). Therefore, the concept focuses more on the ability of actors to access certain resources rather than the resources that organizations possess (Spigel & Harrison, 2018). Their *coordination mechanisms* must find a balance between change and stability to align the power relations within the ecosystem (Autio & Thomas, 2021). The success of ecosystems goes beyond industry-specific knowledge, as they require additional interactions, for instance with policymakers, as they also strive for new institutions to legitimize their proposed collective system-level output (Spigel & Harrison, 2018; Thomas & Ritala, 2022). For a process-oriented perspective, we must deepen our understanding of the complexity and interrelatedness as well as their spatial and temporal dynamics (Lange & Schmidt, 2021).

An ecosystem consists of various actors that fulfill different purposes toward the creation of collective system-level output. Ecosystems are led by one or more *orchestrators* who act as the focal point in advocating value propositions and shaping the goal and identity of the ecosystem (Gulati et al., 2012; Thomas & Ritala, 2022). *Complementors* provide additional resources to the ecosystem but need to

build legitimacy for their contributions (Jacobides et al., 2018; Thomas & Ritala, 2022). *Users* adopt the value proposition of an ecosystem and can also act as a catalyst by supporting the development (Thomas & Ritala, 2022; Tushman, 1992). *External actors* play a vital role in shaping the environment and discourses of an ecosystem, such as regulators or financial regulators (Garud et al., 2022; Thomas & Ritala, 2022). While the proposed roles in the literature provide a sufficient general understanding of ecosystem participants, the categorizations assume a rather static understanding of the respective competencies. Therefore, empirical studies need to put a stronger emphasis on the dynamic interdependences between the ecosystem participants and their practical and institutional connections.

Future research directions in the ecosystem literature indicate the need for an elaboration of interaction and competition between different ecosystems and the emergence and change of ecosystems (Autio & Thomas, 2021). Hence, the authors call for a more process-oriented view of ecosystems that considers aspects like co-evolution, the importance of historic events, and the role of narratives surrounding the development of an ecosystem. Paper 4 of this cumulative thesis empirically investigates ecosystem emergence, with a special emphasis on the legitimacy emergence of young ecosystems that address new digital technologies.

2.5 Synthesis of the theoretical approaches

The proposed theoretical research avenues exemplify the importance of more elaborate and detailed concepts for empirically engaging with the connection between agency and structural change. Evolutionary economics, more specifically EEG, serves as an overlaying paradigm that, however, must overcome its bias on regional development and link better to the micro-level foundations of structural change. A promising framework for this purpose is the trinity of change agency, which highlights distinct but intertwined dimensions of change agency and emphasizes their interdependencies. Transition studies and the multi-level perspective foreground the role of small socio-technical niches where innovation developments are facilitated by a small group of actors who must break with existing structures and paradigms within the socio-technical regime. Ecosystem literature also points out the importance of bottom-up developments with a stronger focus on the role of entrepreneurship that evolves mutually alongside top-down policy decisions. Moreover, the emergence of ecosystems is closely tied to the legitimacy-making of the ecosystem value propositions. While this thesis does not follow the approach of a comparative study in terms of theoretical insights, the different theoretical avenues proposed for the empirical analysis share common goals to strengthen our understanding of human agency and its linkage to geographic research. Table 1 summarizes the main theoretical approaches of this thesis in a comparative overview.

Table 1: Comparison of the main theoretical approaches in this thesis, own elaboration based on the theoretical literature (see Geels, 2002, 2011; Grillitsch & Sotarauta, 2020; Autio & Thomas, 2021).

	Multi-level perspective	*Trinity of change agency*	*Entrepreneurial ecosystems*
Theoretical background	Sociology Evolutionary Economics	EEG Schumpeterianism Institutional theory	Management studies
Analytical levels	**Landscape:** Overlaying slow-paced developments **Regime:** Dynamically stable socio-technical configurations **Niches:** Small protective spaces where novelty evolves Analytical levels are in a hierarchical interdependence.	**Innovative** entrepreneurship **Institutional** entrepreneurship **Place-based** leadership Synthesis of these dimensions drives regional development.	**Actor types**: Orchestrators Complementors, users, external actors **Performative** and **discursive** levels of change Actor-centered and intra-ecosystem perspective.
Propositions and problem definition	**Structural preconditions** in the socio-technical regime determine the system. **Windows of opportunity** enable new breakthroughs from niche developments. Multi-dimensional **co-learning** of actors within the niches.	**Opportunity spaces** as mediators between agency and structure. Some **regions** grow more than others due to **exploitation** of opportunity spaces. Identifying the **rationales**, **strategies**, and **consequences** of agency to explain how paths develop over time.	Innovations must overcome their **liability of newness.** How can entrepreneurs **access** relevant resources to create a **collective system-level output?** **Heterogenous** actors act **voluntarily** and **interdependent** through **coordinating** mechanisms.
Role of place and scale	No geographic dimension in the original framework. Spatial understanding of the analytical levels must be applied by scholars.	Grounded in a geographic understanding of regional path emergence.	Ecosystems generally regarded as local phenomena. Narrow consideration of multi-scalar developments.
Empirical focus	Long-term change Transformative change Sustainability transitions	Path creation Transformative regional change	Established ecosystems Small-scale/Use-case specific Entrepreneurship
Notable research gaps and criticism	Broad framework requires stronger analysis of micro-level processes and agency Landscape (e.g. discourses) only a residual category Broaden perspective beyond typical green technologies	Investigate regional paths that diverge from regional preconditions Dynamic relation of agency and actors; Single actors can combine all the types of agency or they can be split among different actors	Diffuse terminology Emergence of ecosystems Deeper engagement with spatiotemporal effects Static understanding of actor types and their roles

The main common assumption among the theoretical avenues is that individual decisions matter but are embedded in a *complex and multi-scalar environment* where overlaying structural dynamics, top-down decisions, or the persistence of formal and informal institutions can strongly impact the emergence of new technologies. Hence, change agency is no one-way road tied to monocausal relationships, but also

sensitive to disruptive events and the unintended outcomes of intended actions. Therefore, the perspective in this thesis emphasizes a *process-oriented perspective* on agency, where the interdependencies between different scales and places matter, for instance regarding the legal embeddedness of emerging technology and the creation of new policy frameworks. Agency must be understood as a dynamic and varying process of change and exchange, where conflicts, societal barriers, or competition between different actors may ultimately benefit or hinder the emergence of a novelty. As another focal point, this thesis calls attention to the importance of the *discursive levels of change*, assuming that socio-technical change and economic innovation are heavily influenced or even dependent on exogenous impact and narratives surrounding new development.

3. Urban transport innovations in the context of Industry 4.0

The following chapter provides an overview of the empirical embedding of this thesis. Firstly, I outline my personal background that motivated me to engage with this research topic. Secondly, I contextualize the empirical field of "urban transport innovations".

3.1 Personal background and motivation

The original motivation for writing this doctoral thesis dates back to the work on my master´s thesis and work at the Fraunhofer IAO in Stuttgart (see chapter 4.2). In my master´s studies, I engaged with the theoretical avenue of evolutionary economics, not limited to EEG but also interdisciplinary frameworks and research strands. Hence, I was interested in further applying these understandings in a suitable empirical context. I have always had a special interest in digital technologies and foresight studies that engage with future scenarios of how society and Industry 4.0 will ultimately co-evolve (Frey & Osborne, 2017; Zuboff, 1988).

During my work on applied research projects on urban logistics and the piloting of new technological solutions, I gained initial insights that proved to be important to identify research gaps. First empirical observations taught me that urban policymakers often appear to be enthusiastic on the outside when it comes to advertising the use of new technological solutions, but the belief in the practical benefits seemed restrained. Different expectations among various stakeholders often result in the unwillingness to invest time and resources for adequate learning processes and understanding of new technologies. Moreover, bureaucracy and internal coordination processes greatly slow down the exchange and development of new ideas. Temporary projects often lack a sufficient legitimation strategy that focuses on technological upgrading in the long term. Instead, applied research projects often rely on short-term experimentation and run short of a clear future scenario for socio-technical change. This raises the question of whether urban planning should focus on experimentalism alone or build on an integrative and transformative approach (Lange & Knieling, 2020). These phenomena can potentially be reinforced by top-down management (in both public administration and the private sector), which is more

concerned with fast outcomes. Overcoming these formal and informal barriers by individual actors appeared to be one of the main issues when it comes to the acceleration and up-scaling of promising innovation.

In summary, several critical fields of the empirical debate regarding Industry 4.0 became apparent to me through early empirical and theoretical engagement. For contemporary urban development, key factors such as a sensitive assessment between social responsibilities, ecological necessities, economic demand, and the specific infrastructure of a city must be considered and managed by the actors involved. This includes the consideration of the periphery and how discourses and socio-technical upgrading within metropolitan areas can potentially lead to a digital divide between cities and regions (Hindman, 2000). Hence, questions that remained for me were: Which parameters or actors lead to the successful integration of digital solutions in some locations, while others appear to be less successful or even hinder basic developments toward digital transformation? How do individual ideas translate from pure experimentation to a far-reaching solution? And to what extent do (sometimes seemingly trivial) actions of involved actors impact and even shape the structures of urban policy and technological development?

3.2 Contextualizing urban transport innovations

Empirically, I focus on the technological side ("Industry 4.0"-related innovations) and associated societal developments affected by (e.g., sustainability transitions) or created by Industry 4.0 (e.g., platform urbanism, IoT). An in-depth discussion of Industry 4.0 as a vision and synonym for the fourth industrial revolution and its associated technologies is part of paper 1. The debates regarding these emerging technologies range from the reorganization of production and value chains, new industry and market creation, business model innovation, and how these will ultimately impact society as a whole (De Propris & Bailey, 2021; Oztemel & Gursev, 2020; Strange & Zucchella, 2017). One debate that deserves special mention and has been established as one of the most thriving discussions is the impact of Industry 4.0 on labor transformation and how it might substitute or polarize labor in the future (Frey & Osborne, 2017). Besides technological-centered utopia on the outcomes of this disruptive digital change, a growing body of research critically questions how modern Industry 4.0-related technologies enable cities to control available resources more efficiently and sustainable and how they can improve economic and societal outcomes at the same time (Bibri & Krogstie, 2017; Lynch, 2020).

One special interest in this cumulative thesis lies in IoT technologies. IoT solutions in an industrial sense can be defined as follows: "A system comprising networked smart objects, cyber-physical assets, associated generic information technologies and optional cloud or edge computing platforms, which enable real-time, intelligent, and autonomous access, collection, analysis, communications, and exchange of process, product and/or service information, within the industrial environment, so as to optimize overall production value. This value may include; improving product or service delivery, boosting productivity, reducing labor costs, reducing energy consumption, and reducing the build-to-

order cycle (Boyes et al., 2018, pp. 3)." The aggregation and reliable processing of high volumes of data create the potential for new products and valuable services (Alcácer & Cruz-Machado, 2019). Besides manufacturing, the transportation sector is the second largest market for IoT applications, as primarily cities increasingly aim at optimizing their public transportation, improving safety issues, or reducing the impact of air congestion (Sadiku et al., 2017). Thus, interest is increasingly focused on those sectors where demand for sustainable development is high and restructuring of the city is essential. These technological avenues link to narratives such as the smart city (Cocchia, 2014), which also involves the risk of greenwashing (Bibri & Krogstie, 2017). Hence, the term "smart" is often used as a buzzword that implies multiple and diffuse understandings of what a smart city is (Trencher, 2019). The interplay of digitalization and sustainable development poses a great challenge to urban policies and entails several implications for geography (Coenen et al., 2015; Köhler et al., 2019). Overlaying discourses can thus differ from the actual benefits of an implemented technology. Moreover, an urban policy needs to understand citizens and other involved stakeholders as co-creators and contributors rather than simple users (Mello Rose, 2022). Scholars are therefore interested in the analysis of urban experimentation and urban living labs to overcome these shortcomings of smart city development (Bulkeley et al., 2016; Marvin et al., 2018).

What becomes apparent at this point of the discussion, is that the terminology of the "urban" and technologies within cities play a predominant role in the discourse on digital innovations. As some authors highlight, cities can be powerful promoters of emerging technologies, as they provide crucial resources for these endeavors (Truffer & Coenen, 2012). This accounts especially for urban tech that clusters in specialized regions that are tied to the innovation capabilities of metropolitan areas (Florida et al., 2017). While the "urban" seems to matter in the innovation development toward Industry 4.0, we run the risk of a normative understanding of opposites like center and periphery (Glückler et al., 2022). Therefore, we must care to not form a bias in expecting that emerging digital technologies would always be best integrated within an urban context or that the innovation capabilities for this development can only be found in clustered areas.

Setting the scale of this research, it becomes apparent that most intelligent transport systems are strongly reliant on urban narratives (e.g., smart city), and applied research projects primarily evolve in urban contexts, due to the higher availability of funding resources and the persistence of social and environmental issues. Even though the focal point of this thesis is not the terminology of center and periphery, I strongly consider multi-scale interactions and potential impact on rural and peripheral areas in my empirical studies, for instance how discourses emerging in an urban context can translate into business models for regional purposes. Hence, this thesis acknowledges the importance of urban agglomerations for innovation development, while paying attention to the shortcomings of this perspective at the same time. I pay special attention to the distinction between discursive and performative outcomes of innovations, as narratives implying a specific use case could unintentionally

create new paths and business models for other use cases. This aspect can be linked to the theoretical assumption regarding agency, which indicates the importance of the unintended outcome of intended actions.

4. Research design and methodological approach

The first subsection of this chapter summarizes the research design of this cumulative thesis and provides an overview of the methodological approaches. A detailed list of the interviewees and further empirical sources is part of the respective paper. In the second subsection, I provide an overview of the applied research projects that I have been part of during this thesis.

4.1 Qualitative research design

Figure 2 summarizes the research design of this cumulative thesis. The methodological approach is centered around a qualitative social research design, which aims at an exploratory understanding of so far understudied empirical research fields. For this purpose, the papers rely on various methods, namely semi-structured expert interviews, insights from research projects, a systemic literature review, network analysis, and document analysis.

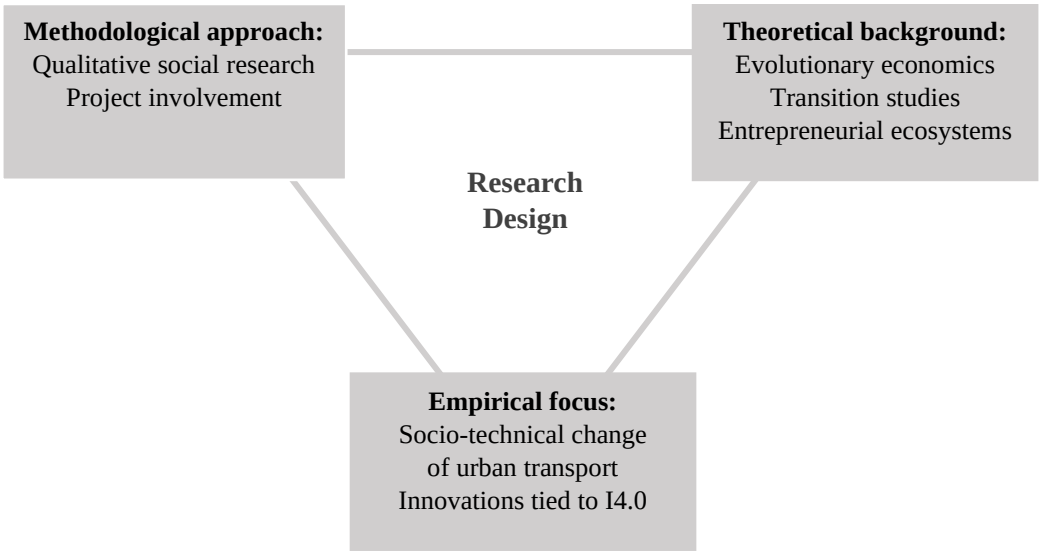

Figure 2: Research design of the doctoral thesis.

In addition to being part of the applied research projects, semi-structured expert interviews served as the primary source for the case studies. The terminology "expert" refers to representatives and individuals in a specific function, which means that they must be treated not only as knowledge providers but also as stakeholders with their specific interests (Meuser & Nagel, 2002). The historic differentiation of the term is closely tied to the development of different professional roles, both within companies, politics, and beyond, such as civil society actors (Bohnsack et al., 2018). The knowledge of an interviewee must therefore always be reflected according to his or her particular field of activity, such as the expertise of

a data scientist regarding software development in his or her company (Nohl, 2008). To fulfill this precondition, there must be a link between the empirical direction of the research and the functional role of the expert (Bohnsack et al., 2018). To support the interviews, a guideline was designed for each interview (see appendix), which was forwarded to the interviewees beforehand. The guideline aims to structure the interviews and to cover certain topics without predetermining them in their entirety (Lamnek & Krell, 2005). The Interviews were subsequently coded using MAXQDA and categorized based on the respective theoretical frameworks. Interviewees included entrepreneurs, especially CEOs and technical developers in senior positions, as well as stakeholders from the city administration, cluster management, or other political positions.

Furthermore, I conduct a systematic literature review in paper 1. The methodological approach of the systematic literature review consists of five research steps: Question formulation, locating studies, study selection and evaluation, analysis, and synthesis, and reporting and using the results (Denyer & Tranfield, 2009). Hence, I aim to identify the current linkages between debates in economic geography and Industry 4.0 and subsequently discuss these findings based on their contributions and research gaps. As an additional method, we conduct a social network analysis in paper 4 to delimit the entrepreneurial ecosystem and identify the ecosystem participants. Hence, it must be highlighted that the network analysis in this thesis fulfills a rather minor and descriptive role that sets the tone for further qualitative approaches. Therefore, the method should not be mistaken for a more in-depth social network analysis, which has significantly stronger quantitative implications. Finally, I use document analysis as a supporting element in the case studies. In particular, I examine policy papers (e.g., from the EU) as well as media coverage of specific technological developments. Table 2 provides an overview of the four research papers that are part of this cumulative thesis. At the time of submission of the dissertation, two papers are published in academic journals, while two others are under review. Moreover, two papers are single authored, while two others are co-authored with one additional author (Paper 2) and two additional authors (Paper 4). While the contribution of the co-author in paper 2 was purely regarding organizational matters, paper 4 was created in close and steady exchange with the co-authors. They primarily contributed to the network analysis and theoretical embedding of the case study.

Table 2: Overview of the research papers of the cumulative thesis.

No.	Title	Type	Status	Own contribution
1	Industry 4.0 and its geographies: A systematic literature review and the identification of new research avenues	Systematic literature review	Published in: Digital Geography and Society	Single-authored
2	Toward smart and sustainable traffic solutions: a case study of the geography of transitions in urban logistics	Case study	Published in: Sustainability: Science, Practice and Policy	Co-authored, 95 % own contribution
3	Change agency and path creation toward future transport systems: The case of urban air mobility in Germany	Case study	Under review Working paper published in Papers in Economic Geography and Innovation Studies	Single-authored
4	Legitimation strategies for digital transformation: Insights from the advanced air mobility ecosystem in Hamburg	Case study	Under review	Co-authored, 70 % own contribution

4.2 Research projects

In addition to qualitative research methods, the findings in this dissertation are also linked to my involvement in applied research projects. Thus, I was directly employed in two projects during my thesis runtime: A project on testing digital delivery zones at Fraunhofer IAO in Stuttgart (Paper 2) and one project on scenario development of urban air mobility at HafenCity University Hamburg (Paper 3 and 4). Moreover, insights from additional projects on urban air mobility in Hamburg were integrated in a co-authored publication (Paper 4). In the following, I provide a short introduction of the respective projects, my role, and tasks as well as their contribution to the thesis.

Research project 1

The first project “SmartZone” at Fraunhofer IAO is concerned with the integration of digital delivery zones as a supporting tool for urban logistics. The project was carried out in close cooperation with a Spanish software developer who originally designed the innovation in Barcelona and deployed it area-wide for the first time. I originally started working on this topic during my master's thesis and continued the empirical and theoretical analysis afterward, so the case study simultaneously represents the bridge from my initial motivation to the research design of my doctoral thesis. The technology aims to improve the management and assignment of delivery zones within a city while simultaneously increasing the transparency of commercial traffic. For this purpose, specific spaces for logistics companies to load and unload are designated with a specific traffic sign and are connected to an app-driven platform via a Bluetooth device. The delivery process is then started automatically via the app on the driver's smartphone. This process intends to contribute to the following problems in city logistics: (1) an increase

in traffic turnover and the prevention of informal and congestive behavior such as second-row parking; (2) to allocate urban space to specific use cases and provide better monitoring of parking duration and permits; (3) contribute to the local reduction of environmental pollution through regulatory measures such as low-emission zones; (4) establish a big data platform for urban planning to obtain a well-founded understanding of commercial traffic and to be more flexible in responding to demands and challenges.

My role in the project was to coordinate the exchange with the Spanish partners and to jointly implement a pilot project for the technology in Stuttgart. This included regular coordination meetings, workshops with the city administration, and the evaluation of possible implementation scenarios. Building on these findings, I also conducted further empirical research, which forms the basis for paper 2. This included a trip to Barcelona, where I conducted additional expert interviews and participatory observation. The project participation thus not only served as an initiator for the idea of the first case study but at the same time provided internal insights regarding the benefits and barriers of the technology, which were reflected in the discussion of the paper. In addition, the importance of a geographic perspective became clear in the course of the work, since only the testing of the technology in various locations with different institutional frameworks led to successful integration. Being part of this co-learning process greatly enriched my understanding of the socio-technical change and

Research project 2

The second project involvement relates to the "i-LUM" (Innovative airborne urban mobility) project at HafenCity University Hamburg. The project is one of three projects (at the time of this publication) at the working group Digital City Science that deals with the urban integration of AAM in Hamburg (see Fraske et al., 2022). The project aims to elaborate and evaluate methodological, systemic, and knowledge-based foundations of the feasibility of AAM. The interdisciplinary findings should ultimately lead to a holistic understanding of these innovative concepts and technologies and translate into future scenarios for AAM in the metropolitan area of Hamburg in the years 2040/2050. For this purpose, the project bundles insights from multiple disciplines, which resemble the five main work packages of the project: (1) social interactions & legal frameworks, which include acceptance, psychological, and law implications for AAM; (2) demand Modeling and Concept Development, which concerns demand forecasting and identifying potential user groups; (3) ground-based infrastructure, dealing with the networks, maintenance, energy systems, and urban integration of AAM; (4) airspace organization and operations, which summarizes the main technical aspects, such as flight trajectories; (5) an overall system modeling and evaluation of the different research strands. While the different research groups also focus on specific and individual questions surrounding AAM, the overarching goal is to develop an overall simulation of AAM in Hamburg, which quantifies the main parameters and provides a data platform for future research and development for that emerging technology.

My primary tasks in the project included the management of work package three concerning the ground-based infrastructure of AAM. My research primarily addressed questions regarding urban planning matters and socio-technical integration of AAM, while also participating in interdisciplinary publications (Mavraj et al., 2022) and conference attendances. The insights thus provided me with a broad overview of the empirical topic, both theoretical and practical. While the steady exchange with engineers and software developers was crucial to gain an in-depth perspective on the technological side of AAM, I also frequently discussed these topics with other social scientists, public actors, and entrepreneurs. These initial insights laid the basis for two case studies I conducted and included as part of this PhD thesis (Paper 3 and 4).

Additional insights

In addition to the aforementioned projects with direct involvement, I was also embedded in the wider procedures and exchanges of the respective working groups. Especially in the working group Digital City Science of the HafenCity University Hamburg, I gained deeper insights into software development for tools supporting contemporary urban planning. Two specific projects were of special relevance, addressing urban air mobility as a subject: Firstly, the Medifly project, which elaborates on the use of transport drones for medical purposes (e.g., transport of tissue samples) between hospitals in Hamburg. In addition, the project obtained findings on the social acceptance of this new form of mobility using participative methods. Secondly, the LUV project draws up legal recommendations for the U-space proposal of the EU and transfers these insights to the national context. Impressions from both projects serve as additional empirical sources in paper 4.

5. Contributions

As shown in the methodological overview, the cumulative thesis consists of four independent papers with different thematic and contextual focal points. While all works are located within the theoretical operationalization as well as the elaborated research design, they are to be considered autonomous in their analytical contributions. Despite different conceptual frameworks and empirical fields of investigation, they all contribute to answering the overarching research questions regarding the human agency of emerging technologies in the context of Industry 4.0. In the following, I provide a concise overview of the individual contributions and their theoretical and empirical embedding.

Paper 1

The first publication, titled "*Industry 4.0 and its geographies: A systematic literature review and the identification of new research avenues*", provides a holistic overview of the state-of-the-art research published on the economic geography and spatial implications of the fourth industrial revolution. It was published in the journal *Digital Geography and Society* in February 2022. The paper primarily addresses the first overarching research question (RQ1) by systematically categorizing and evaluating the current

research state and subsequently identifying research gaps. The article follows the research question: *"How can geographies contribute to the understanding of Industry 4.0?"*. The article primarily acts as an aggregator for empirical insights on Industry 4.0 in economic geography (Balland & Boschma, 2021; De Propris & Bailey, 2021) and also adds to the emerging research body on digital geographies (Ash et al., 2018; Haefner & Sternberg, 2020). The review deliberately takes a more far-reaching perspective that goes beyond the empirical focus on the transport sector in this thesis. This is motivated partly by the limited research on the topic to date, and by the necessity to address the cross-sectoral application areas of the emerging technologies. Thus, IoT or Big Data applications must be understood as dynamic solutions for problem-solving, which are transferred to various existing sectors or infrastructures. In addition, societal conflict fields, for example in terms of cyber security or social acceptance of autonomous vehicles, are also expressed alongside these overarching narratives. To the best of my knowledge, this is the first review of its kind to present a systematic overview of economic geography and Industry 4.0 and should serve as a conceptual basis for the empirical work of this thesis.

The review draws on the academic database Web of Science and considers all publications between January 2011 and December 2021. Based on defined inclusion/exclusion criteria, it includes 177 papers in the final analysis. After an in-depth screening of the involved publications, five main topics of the current research become apparent: (1) value chains and supply networks; (2) clusters and industrial districts; (3) readiness and adaptation of regional industries; (4) innovation development and ecosystems; (5) labor market. As a central observation of the literature analysis, it can be noted that the embedding in theoretical fields of economic geography is very thin at present. Neighboring disciplines account for a large part of the publications, which nevertheless leads to a rather superficial discussion of the role of space and scale. These research gaps accentuated in the discussion chapter include the time and space-specific opportunity spaces of emerging technologies, the connection of structural preconditions and human agency, the emergence of platform urbanism, and how discourses shape expectations and niche creation for innovations. In addition, a more sensitive and empirically grounded debate must be conducted regarding the positive or negative outcomes of Industry 4.0 As these debates are strongly guided by conceptual paradigms, we learn little about measurable impacts on spatial inequality, sustainability, or the renegotiation of spatial relations. Moreover, there needs to be a stronger emphasis on how digitally mediated knowledge and geographies of and by the digital itself can create new promising research avenues for geographers. The review proposes a list of future research questions and concludes that geographers need to engage more strongly with this research topic complementary to the techno-centric and business-oriented understanding of Industry 4.0.

Paper 2

The first case study of this thesis, named "*Toward smart and sustainable traffic solutions: a case study of the geography of transitions in urban logistics*", was published in December 2020 in the journal

Sustainability: Science, Practice, and Policy. It is part of a special issue on the cultural dimensions of mobility transitions to come (Sonnberger & Graf, 2021). The article inquires into the cross-sectoral and multi-scalar dimension of human agency (RQ3), while also addressing the impact of agency on the success of an innovation (RQ2) and the combination of different theoretical frameworks (RQ4). I investigate the integration of an app based IoT solution to regulate economic transport and delivery traffic in Barcelona via smart loading zones. To do so, I answer two research questions: "*How can urban policies support the geographic transition of an innovation? And how can the interplay of changed practices, involved actors, and pathways lead to a successful transition?*". Theoretically, the study combines insights from transition studies and economic geography. It builds on the established framework of the multi-level perspective (Geels, 2002; Geels & Schot, 2007) and the debate on sustainability transitions (Köhler et al., 2019; Hansen & Coenen, 2015) and enriches it with a spatial perspective and a special emphasis on the role of the involved actors, changed practices, and pathways (Fastenrath & Braun, 2018). The main contribution of the article lies in the empirical demonstration of how the practices of a single actor can enforce structural change and what adaptive capabilities are required to overcome existing barriers in the socio-technical system. Moreover, it underscores the importance of a geographic understanding of socio-technical transitions and a refinement of the multi-level perspective that considers multi-scaler processes of co-learning.

Methodologically, the article draws on three different sources. Firstly, the paper is closely tied to the first applied research project at Fraunhofer IAO. Hence, I worked closely with the developers of the technology in Barcelona for over a year and participated in the realization of a pilot project in Stuttgart, including workshops and exchanges with the municipality and the developers (see chapter 4). Secondly, I conducted expert interviews with seven actors, namely software developers, cluster managers, city administrators, and information scientists in Barcelona, to broaden my perspective on the development. Thirdly, I performed participatory observation on sight to gain a better understanding of the general functionality of the technology and the routine change for logisticians. Moreover, I reflected on existing technical reports and publications concerning the technology. The case study shows how urban visions can serve as incubators for innovative developments and support transitions through clear structuring and formal anchoring. Moreover, localized visions can successfully create new socio-spatial pathways, if the interplay between changed practices, learning processes, and the involved actors is successful. While the original technology by the public administration set the foundation of the niche development in a local regime, an upgraded version, developed by a single pioneer who founded a start-up, managed to create markets for smart loading zones in other geographic regimes. Regarding the question of how cities shape wider institutional change beyond their initial geography (Turnheim et al., 2018), I observed an unintended upscaling of the actual idea. Although marketing the technology outside the city was not originally intended, this was made possible by the further efforts of the transition agent. This shows the need for individual actors who are willing to progress the innovation beyond the original geographic

context and, moreover, the need to access other geographic locations with different institutional preconditions.

Paper 3

The third article titled "*Change agency and path creation toward future transport systems: The case of urban air mobility in Germany*" is the first of two case studies with a focal point on the emergence of air mobility and its associated technologies. In contrast to the other case studies, this paper puts a strong emphasis on macro-level development and tries to identify the multi-scalar connections between national, regional, and local dynamics of emerging technologies. Therefore, it refers particularly to RQ3. The article is currently under review, a preprint version was published in the working paper series *Papers in Economic Geography and Innovation Studies* (University of Vienna) in July 2022. The article theoretically relates to the theoretical debate about the trinity of change agency (Grillitsch & Sotarauta, 2020) by applying this concept to an empirical case and deriving conceptual inferences from it. The research questions are therefore: *"How can the trinity of change agency contribute to the understanding of path creation toward urban air mobility? To what extent can this case contribute to our conceptualization of change agency?"*. The paper builds on recent contributions to the topic of emerging industries, institutions, legitimacy, and agency (Gong et al., 2022; Grillitsch et al., 2022) and the interconnectedness between technological characteristics and regional development (Gherhes et al., 2022; Njøs et al., 2020). The added value can thus be found primarily in two aspects: Firstly, this study is the first of its kind to take an analytical look at the innovation development of advanced air mobility in Germany from a regional economic perspective. In this context, I reflect on the socio-technical challenges in entrepreneurship to access opportunity spaces, legal framework requirements as well as the formation of regional clusters. Secondly, the study concludes the conceptual validity of the theoretical framework, pointing especially to interdependencies and the importance of institutional constraints between the different agency types.

The purpose of this case study has been materialized by conducting semi-structured expert interviews with entrepreneurs and policy actors that are involved in the development of the urban air mobility sector. A total of 22 interviewees from 19 different organizations participated in the investigation. Moreover, the study is loosely tied to the second project involvement, as I included insights from my previous work on the topic and the constant exchange with the municipality and local actors in Hamburg. Public documents and media coverage supplement the primary empirical sources. The empirical results find that the socio-technical integration of air mobility in Germany and the emergence of opportunity spaces is centered around institutional entrepreneurship and the importance of formal lawmaking and the creation of legitimacy, both within the sector and toward society. This is exemplified by the dominant role of certain actors in the overall development, namely the European Union, the DFS (German Aviation Safety Agency), and venture capitalists. Industrial development is characterized by two

different groups of entrepreneurs who approach this field, namely the aviation sector and software developers with a background in IoT and artificial intelligence. As the perception and expectations surrounding this new mobility form differ greatly among entrepreneurs, policy actors, and society, the study indicates the importance of discourses and the sovereignty of interpretation for the success of emerging technologies. This is reflected in the unification of air taxis and drones in the discourse, even though technical developers stress the fundamental difference in the design of the respective technologies. The regional clusters in Hamburg, Aachen, Ingolstadt, North Hesse, and Berlin form closely around existing regional preconditions. While there is competition regarding funding for pilot projects among the clusters, they primarily aim to collaborate and bring up common goals toward the national and European policy levels. This intent is primarily driven by the fear of being overwhelmed by the socio-technical integration once the legal framework is set, so there is a strong effort to incorporate regional interests at an early stage.

Paper 4

The fourth and final article titled "*Legitimation strategies for digital transformation: Insights from the advanced air mobility ecosystem in Hamburg*" builds on the conclusion of paper 3 by taking an in-depth perspective on a local entrepreneurial ecosystem and the legitimacy emergence of AAM. The article is currently under review in a journal. Based on the overlaying research questions, it primarily addresses the positive or negative impact of human agency on innovation development (RQ 2). The research refers to state-of-the-art conceptual frameworks regarding legitimacy emergence in entrepreneurial ecosystems and how organizations engaging in digital transformation legitimize their new value propositions (Autio & Thomas, 2020; Thomas & Ritala, 2022). Therefore, the article inquires into the question of *how participants of entrepreneurial ecosystems, that engage in digital transformation, reduce their liability of newness*. We further disentangle this research question into two sub-questions about *(1) how an emerging digital transformation ecosystem is structured* and *(2) what legitimizing strategies emanate from the coordinated actions of its participants*. Organizations engaging with digital transformations face a variety of organizational, legal, and social barriers (such as disbelief or lack or viability of the innovation) which we refer to as liability of newness (Aldrich & Fiol, 1994; Stinchcombe, 2000). We understand digital transformation as a collective endeavor of heterogeneous participants with different roles within an ecosystem, who aim at performing a collective system-level output through inter-organizational collaboration (Hinings et al., 2018; Nambisan et al., 2019). Hence, the main value of the article lies in the empirically grounded refinement of the theoretical framework by identifying the local causalities of ecosystem legitimacy emergence in the case of the AAM ecosystem in Hamburg.

The methodological approach relies on three sources: Firstly, we carried out a network analysis to delimit the ecosystem and contextualize our case study. Through online data sources and snowball sampling, we provide a holistic overview of the ecosystem participants and categorize them based on

their background and project involvement. Secondly, the case study draws on insights from the conducted expert interviews in paper 3. Thirdly, we refer to internal insights and participatory observation from three applied research projects at HafenCity University Hamburg, which provide us with an interdisciplinary perspective on the development of AAM (see chapter 4.2). In the empirical analysis, we distinguish the discursive and performative dimensions of legitimation in the AAM ecosystem in Hamburg. Discursive legitimation resembles the current discourses and narratives surrounding the development of AAM to promote the comprehensibility of the ecosystem, both inside and outside of the metropolitan area. Performative legitimation covers the practical outcomes of the strategic actions by the involved actors to strengthen the viability of the ecosystem. We find that while there are many attempts for strategic action to process the innovation, the ecosystem overall lacks a clear identity and framing. While most actors praise the engagement of the local network initiative Windrove, many participants criticize the lack of an ecosystem orchestrator and feel great uncertainty at this point of development. Only a few participants have a direct impact on shaping regulations and are strongly dependent on actors and decisions made on the national scale. The industrial development is also strongly influenced by the existing aviation industry, whereas authorities and companies remain hesitant to engage with air taxis, as these discourses are still regarded as dystopian futures that could potentially also hinder the integration of drones for other transport purposes. Hence, two theoretical implications derive from this case study: Firstly, we highlight the necessity to consider existing hierarchies and legal responsibilities of the involved actors and how ecosystems are interwoven or co-evolve with other spatial phenomena like clusters or regional innovation systems. This links to a stronger empirical engagement of combining these concepts in academics and how they can mutually benefit each other. Secondly, we question the rather peripheral role of external actors (such as regulators) in ecosystem literature. In our case study, it becomes apparent that public-private actors fulfill a double role in the sense that they are embedded in the ecosystem and market creation while maintaining an authority function. Hence, they provide orchestrating activities but have the ability for top-down decision-making at the same time. This would call for a more differentiated perspective on the individual roles of ecosystem participants and their institutional impact.

6. Conclusions

The following chapter concisely summarizes the main findings of this thesis. The case-specific conclusions are discussed in more detail in the respective papers. In addition, I outline limitations, future research avenues, as well as practical implications, which can be derived from the experiences of this thesis.

6.1 Answering the research questions

The overarching starting point of this thesis questions the lack of bridging the conceptual levels of micro and macro-level phenomena in EEG. Therefore, the question was further disentangled into the sub-topics of enforcing and hindering parameters of human agency for innovation, the multi-scalar and cross-sectoral dimensions of this change, and how we can combine different theoretical approaches altogether. The insights from the research within this thesis imply that an in-depth perspective on agency not only enriches our geographic understanding of transformation processes but opens new theoretical and empirical research avenues. While geographers can learn from interdisciplinary discussions, a spatial understanding of Industry 4.0 is crucial to explaining the outcome of human agency and its impact on innovation processes. An EEG perspective needs to pay attention to decision-making, the individual embedding of key actors and identifying sectoral interdependences not only on a regional but also on an actor level. Moreover, the fast-paced developments during digitalization and the associated restructuring of economic and societal structures require a stronger empirical engagement with ongoing activities rather than a bias on historic developments alone.

Human agency can be the driving force for innovation if the key actors fulfill certain conditions. As the Barcelona case shows, there is a need to be aware of local problems in a socio-technical system and translate these practical insights into new ideas. However, overcoming these existing problems implies a certain amount of power (e.g., decision-making within a municipality) to even be able to develop and work on a solution. Moreover, it is crucial to access different geographic regimes with other institutional structures and learn how to further develop an idea based on external feedback and experiences abroad. As the most important parameters to enforce the transferability of innovation, the findings highlight the ability of an actor to access different socio-technical regimes to improve niche development, gain experiences from a broad set of stakeholders, including civil society, and be able to bridge existing with new emerging knowledge bases. The constant adaptation of a digital solution is even more essential because most digital innovations are rarely final or completed products, but only generate their added value through flexible and continuous adaptation (e.g., through real-time data). Understanding and participating in their local environment and building upon regional preconditions are equally important as trans-local learning processes and the exchange of knowledge.

The most crucial barrier factors turned out to be persistent formal institutions and the lack of willingness to learn or sensitization of key actors within the socio-technical regime. Especially public-owned companies stood out as a strong factor in AAM development, as they possess crucial resources or even a monopoly in certain areas (such as the definition of legal airspace) while participating in the commercial market at the same time. These structures not only create very biased and anti-participatory decision-making processes but also discourage actors from engaging with a particular technology. It also runs the risk of venture capitalists withdrawing, delaying developments unnecessarily, or

entrepreneurs shifting their activities abroad. Hence, the state and/or policy needs to take care that not too many competencies are bundled within one key actor alone. Moreover, insufficient co-learning toward new technological configurations may lead to elitist business models that do not cover the needs of most of the population, as exemplified in the air taxi development so far.

One apparent yet interesting observation is that the integration of digital innovations within existing sectors is rather fragmented and rarely established in a broad sense. As highlighted in the literature review, while the discourses on how Industry 4.0 will reshape labor and regional economics are thriving, there are only a few observable impacts of these developments so far. Especially formal institutions seem to be more persistent than expected, which can also be observed in the case of AAM. However, these institutional settings differ greatly on a global scale and can hence have a strong impact on local development. This is exemplified by the different pace of the development toward the integration of AAM, which faces more policy barriers in Europe than in China or the US. Moreover, specific use cases (e.g., drones in agriculture or military) that act as an accelerator for further technological development (e.g., air taxis) are unevenly distributed spatially. Previous investments and associated sectors have a strong influence on the accumulation of venture capital and consequently on the development of incremental innovations. In addition, legal frameworks are more flexible if they have already been sensitized to a particular technology in one place and are thus easier to adjust, e.g., adapting existing drone laws for more extensive air taxi use. The lack of such a legal framework has been the biggest obstacle for entrepreneurs and other stakeholders in Germany so far.

Once a new technology is integrated into a new socio-technical regime, it faces the challenge of overcoming existing routines in its established sector. As transition studies emphasize, a successful transition is not defined by the marketability of the invention, but primarily by addressing all established elements within the system. As experienced in the case of urban logistics, an innovation requires sensitizing the foundations of an existing regime, namely the routines of the logistics drivers. These changes can be very trivial, like the simple push of a button during a parking process, but they require larger participation efforts with the relevant target group. This underlines that social acceptance should not be seen as a purely measurable parameter but should be specifically and spatially tailored to the respective objectives.

As noted in the theory chapter, the synthesis of the theoretical approaches can be summarized in the overlaying assumptions on agency: the interaction with a complex and multi-scalar environment, understanding agency from a process-oriented perspective, and the impact of discursive levels of change. While all theories and conceptual frameworks have proven to contain some distinct strengths, certain shortcomings became apparent during the case studies. EEG provides us with an in-depth understanding of regional and sectoral development but misses linkages and explanations of micro-level phenomena. Combining insights from geography and transition studies led to a thriving debate and

theoretical contributions about how to better understand the causalities between agency and structure, such as understanding socio-technical niches as collective and actor-driven spaces that are at the same time transferable and adaptable to different environments.

Even though a synthesis is possible, there should not be the ultimate aim for creating a holistic framework that covers everything. While there is a common ground in the process-oriented perspective, there are different analytical approaches to understanding the empirical outcomes of a certain case. Rather than streamlining the conceptual approaches, the goal must be a synthesis of the different interpretations to gain the most insights into the empirical domain. Frameworks can co-exist and mutually benefit from each other if we reflect on their strengths in the sense of critical realism, or to put it more precisely: How does a theoretical framework contribute to our empirical observation of human experiences? And to what extent does it enable us to draw conclusions on the domain of reality?

As emphasized particularly in papers 2 and 4, the explanation of the reality lies not in the competition between different frameworks, but rather in the combination of their interpretative analysis for a holistic observation of the empirical. As shown in the case of AAM ecosystems in Hamburg, ecosystems do not emerge out of context, but can be heavily influenced (and legitimized) by existing regional innovations systems or clusters. The outcomes of these interdependencies contribute to our understanding of the overall development. Economic geography is already struggling with a multitude of various paradigms, which led scholars to enforce the idea of an "engaged pluralism" between these different perspectives (Barnes & Sheppard, 2010; Hassink et al., 2014). This dialogue should also be expanded to neighboring disciplines and approaches that have the potential to enrich our theoretical understanding and vice versa. Transitions studies or management studies in the form of entrepreneurial ecosystems are just two promising avenues in this regard. Continuous refinement of these approaches can ensure that we do not run short of a critical reflection on our own research community. Moreover, testing these frameworks in a thriving and emerging research environment such as Industry 4.0 enables us to uncover new dynamics and causalities that may have remained unnoticed so far.

6.2 Limitations and future research avenues

As with any research, this thesis does not come without certain limitations in its theoretical, methodological, and empirical approach. While this thesis combines promising approaches from different theoretical backgrounds with a differentiated understanding of agency, the research primarily relies on the paradigm of evolutionary economics and its geographic offshoot, EEG. Some scholars highlight that socio-technical transitions and path development are not necessarily evolutionary processes, as exemplified in the debate between path dependence and path creation (Garud et al., 2010). Economic geography has undergone a multitude of paradigm shifts, with various key concepts and a different view on place and space (Hassink & Gong, 2017). The findings of this thesis call primarily for a stronger relational and institutional perspective on the processes toward Industry 4.0, such as a deeper

understanding of the role of routines and informal institutions that shape the structural integration of emerging technologies. Future research, therefore, needs to clearly outline the regional potentials and capabilities of new technological endeavors and their regional diversification (Balland & Boschma, 2021). Just as the synthesis of different conceptual frameworks, the complementary analysis with a varying paradigm background could potentially contribute to a better perception of the empirical if seen from an engaged pluralism perspective. Moreover, this study investigates early socio-technical developments. Studying innovative niches, forerunning actors, and emerging technologies might be empirically thrilling and challenge existing frameworks but also poses a risk of hasty conclusions. Digital innovations evolve in a dynamic and multi-faceted environment, and the foresight of future developments needs to be addressed with caution. This circumstance is particularly evident in the conceptual literature on Industry 4.0, as rash assumptions are frequently being made about probable future scenarios, despite insufficient empirical impressions. The aspect of how (especially evolutionary) concepts and theories can cope with this fast-paced development also needs to be critically debated by scholars engaging in this empirical field.

These findings emphasize the basic dimensions of the trinity of change agency and the need to balance innovative, institutional, and place-based competencies. However, there is a lack of understanding of how key actors who do not already possess certain preconditions could be empowered to engage with these changes. As ambitions and know-how alone are not sufficient parameters for a holistic explanation of individual skill, there also needs to be a stronger focus on the mutual relations of the actor in his socio-technical environment. Therefore, windows of opportunity must not be understood as purely technological frames, but must also relate to the actors themselves, who may have to acquire their position in the first place. This would call for a deeper understanding of bottom-up policy approaches or urban grassroots initiatives (Smith et al., 2013; Vadiati, 2022). Particularly in light of digitalization, new types of cooperation and entrepreneurial practices tend to establish themselves, such as the gig economy (Vallas & Schor, 2020). Particularly in precarious or underpaid labor conditions, such as in logistics, such models can act as an additional driver or barrier to technological advances.

The biggest notable research gap, as strongly emphasized in the systematic literature review, lies in the pure engagement of economic geography with empirical topics concerning Industry 4.0 and digitalization. Surprisingly, economic geography accounts only for a fragment of the research on regional and spatial implications of Industry 4.0 so far, hence there are only weak ties to ongoing theoretical debates. Paper 1 outlines several potential future research questions based on the insights of the review. Besides the questions surrounding the socio-technical development enforced by Industry 4.0 itself, there is also a lack of analyzing overlaps with other ongoing transformations, such as the fulfillment of the sustainability goals and how digital innovation can potentially contribute to or counteract these in the future.

Finally, my personal experience while conducting this thesis unveiled the difficulty of addressing interdisciplinary topics beyond the researchers' background. Most papers in this cumulative thesis, at the point of submission, were not cited in economic geography literature but other socio-technical studies on Industry 4.0 or research related to artificial intelligence and IoT. This underscores the challenge of bridging different research strands not only in the research design but also in reaching more than one specific academic community. While the distinction between different academic fields remains a natural circumstance, this thesis should motivate scholars to engage with new perspectives and move out of their respective comfort zone. Just as in socio-technical development, co-learning depends on the willingness to exchange and openness to new things and can expand any actor's horizon.

6.3 Policy and practical implications

Ultimately, this cumulative thesis addresses important aspects to consider for practitioners such as entrepreneurs and urban planners that engage with the emerging topics of IoT in an urban environment. Reflecting on the applied research in which I participated, the main challenge is to find a balance between stakeholders' interests and a fundamental research perspective that entails a critical evaluation. In AAM development in particular, it became clear that the overall niche developments are heavily influenced by either established sectors and global players (such as in aviation) or public companies who hold a monopoly on managing legal frameworks. Practical testing and implementation must incorporate the necessary participatory elements to consider as many actors as possible within these processes. This not only accounts for entrepreneurs and planners, but also for an early sensitization of civil society. Although this aspect may seem like an obvious argument, the reality of many projects falls short of fully understanding the environment in which they operate. Besides top-down decision-making and powerful actors, a simple lack of information can also be highlighted as a crucial blind spot for new path development. For instance, many actors engaging with drones did not even know about existing networks, clusters, or policy frameworks that could potentially help them further develop their ideas. Building a network with open communication channels and establishing actors (or orchestrators and complementors in the narrative of ecosystems) that fulfill this purpose must be a central object for policymakers to initiate. Moreover, the temporary nature of most practical experiences from applied research projects makes it challenging to strengthen the long-term goals of socio-technical development, as the main goal is often the extension of the funding period rather than critically reflecting on the empirical insights. Conclusively, the primary objective must be to overcome pure experimentation and enforce a stronger contemporary element within applied research projects.

Finally, I want to emphasize the significance of my embedding within an interdisciplinary and practical research environment during this thesis. As emphasized in the theory and conclusion chapters, productive interdisciplinary work is a collaborative learning process, rather than a mere integration of distinct elements. Too often we tend to discuss societal or economic outcomes of innovations without

truly engaging with and comprehending the technological and engineering site (and vice versa). This thesis was even more empirically fruitful because of the direct embeddedness in technical-oriented applied research projects. The exchange with engineers, software developers, and CEOs with a technical background on a daily basis is just as important as our rigorous approaches like expert interviews or network analysis. It not only broadens the horizon of the researchers, methodologically and empirically, but it also enriches the theoretical understanding of socio-technical developments by understanding how "the other side" approaches problems.

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Industry 4.0 and its geographies: A systematic literature review and the identification of new research avenues

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ABSTRACT

The purpose of this paper is to provide a systematic literature review of the research published on the economic geography and spatial implications of the fourth industrial revolution ("Industry 4.0") using key terms and inclusion/exclusion criteria. Based on this methodological approach, this review includes 177 papers in the final analysis. I discuss the literature based on primary research strands and their analytical contributions to understanding spatial developments in the context of Industry 4.0. The review highlights five main topics that current research focuses on: (1) Value Chains and supply networks (2) Clusters and industrial districts (3) Readiness and adaptation of regional industries (4) Innovation developments and ecosystems (5) Labor market. In the analysis, it becomes particularly clear that the embedding in the theoretical fields of economic geography is so far very thin. The paper calls for a multi-scalar understanding of Industry 4.0 and outlines future research avenues with a focus on the emerging topic of digital geographies. Scholars need to put an emphasis on the role of the geography of digital innovations within socio-technical systems to better understand the spatial dimensions of the fourth industrial revolution and its impact on the economy, society, and environment.

1. Introduction

The debate on how digitalization affects geography as a science has been of growing interest in recent years (Ash, Kitchin, & Leszczynski, 2018; Leamer & Storper, 2014). For a long time, geography did not pay sufficient attention to the broad discussion of topics related to the "digital" (Haefner & Sternberg, 2020). The actual impact of the "digital turn" within geography remains vague and is still the subject of open debate. Ash et al. (2018) point out that instead of talking about "digital geography" as a whole, it is more meaningful to think of the impact of digitalization on many geographies. For this purpose, it makes sense to link the early innovation developments of Industry 4.0 to ongoing debates in economic geography, rather than thinking of them as an overlaying development.

The main problem that this study attempts to address is the lack of a holistic understanding of the spatial implications of the fourth industrial revolution. So far, we know little about the spatial embedding of Industry 4.0 related technologies, path development, the knowledge creation and learning processes during innovation and adaptation of regional industries, as well as relevant stakeholders that can enable a successful transition (De Propris & Bailey, 2021; Haefner & Sternberg, 2020; Hervas-Oliver, Gonzalez-Alcaide, Rojas-Alvarado, & Monto-Mompo, 2020). This study aims to enrich the techno-centric perspective of Industry 4.0 with a deeper understanding of socio-spatial effects and the role of space and scale. Therefore, the research question is as follows:

"How can geographies contribute to the understanding of Industry 4.0?"

Based on a comprehensive reflection of the existing literature, the paper outlines potential future research avenues with a strong emphasis on the distinction between the micro and macro scale. Besides the importance of contemplating the impact of Industry 4.0 on existing debates in economic geography, there is a necessity to rethink our conception of space, scale, and industrial characteristics in a wider understanding. The fourth industrial revolution not only challenges socio-technical systems through the integration of both incremental and disruptive innovations, but also the actions, perceptions, and imaginations of every individual who engages with these new technological ideas.

As Industry 4.0 is a new and challenging research field, every study engaging in this research has its limitations. Due to the interdisciplinary

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nature of digital geographies, we need to broaden our perspective on economic geography. The developments not only cover pure technological endeavors but also create new societal surroundings. Therefore, I do not only review typical engagements of economic geography like cluster theory, but also consider and discuss aspects regarding labor 4.0, platform urbanism, smart city development, or sustainability transitions. Nevertheless, due to the diversity of the debate, this study cannot guarantee a complete consideration of all potential focal points. Rather, this paper intends to provide a starting point to facilitate access for geographers and motivate scholars to engage in future research.

Economic geography has a historical interest in analyzing and evaluating the causalities of industrial development. Several conceptual approaches and theoretical strands exist that address these developments, including but not limited to clusters, regional innovation systems, or path dependency. One paradigm specifically concerned with these time-specific developments is evolutionary economic geography, as it focuses on "processes by which the economic landscape – the spatial organization of economic production, circulation, exchange, distribution, and consumption – is transformed from within over time" (Boschma & Martin, 2010, p. 6). Empirically, this idea translates into approaches that aim to capture the reciprocity of technological development and exogenous factors like institutions in a region (Murmann & Homburg, 2001). Thus, understanding the spatial implications of industrial development from a geographic perspective is crucial to understanding not only the evolution of regional industries, but their societal and environmental influences as well.

"Industry 4.0" was first announced at the Hannover Fair in 2011 (Drath & Horch, 2014; Oztemel & Gursev, 2020). Besides its German origin, Industry 4.0 has become the most common term for paraphrasing innovative developments during the fourth industrial revolution. Industry 4.0 comprises technologies that connect physical and virtual spaces via smart networks and sensor systems and thus have a fundamental impact on different levels of the value chain, in addition to generating and analyzing large volumes of data (Brettel, Friederichsen, Keller, & Rosenberg, 2014; Lee, Kao, & Yang, 2014; Strange & Zucchella, 2017). Besides these cyber-physical spaces, the idea of the smart or dark factory plays a crucial role in the idea of Industry 4.0, describing a manufacturing process that is fully automated and reduces the human workforce to a minimum (Lucke, Constantinescu, & Westkämper, 2008; Oztemel & Gursev, 2020; Wang, Wan, Li, & Zhang, 2016). Table 1 provides an overview of the key technologies of Industry 4.0 and their general ideas and functions.

The fourth industrial revolution has a mutual impact on the local, regional, and global context and therefore challenges our understanding of space and scale by restructuring value chains and knowledge networks. This raises the question regarding the importance of local and external ties, or prominently referred to as local buzz and global pipelines (Bathelt, Malmberg, & Maskell, 2004), and how entrepreneurs and public actors combine different spatial capabilities for accelerating their ideas and innovations (Grillitsch & Sotarauta, 2020). Industry 4.0 enforces co-evolution between the socio-spatial and technological spheres (Fastenrath & Braun, 2018). Consequently, a rigorous understanding of technological characteristics is crucial to analyze socio-technical path creation (Njøs, Sjøtun, Jakobsen, & Fløysand, 2020). Therefore, we should seize the emerging debate about digital geographies in a theoretically engaging manner that should not run short of linkages to existing contributions within the broad range of geography and its subdisciplines.

The article is structured as follows. The next section provides an overview of the methodology and quantitative aspects of the systematic literature review. In the following, I provide a content analysis where I summarize the state of the art and focus on five research areas. I subsequently discuss the findings and propose research avenues for future studies. The final section concludes the main findings of this review.

Table 1
Key technologies of Industry 4.0, based on Boston Consulting Group, 2016; Alcácer & Cruz-Machado, 2019.

Key Technology of Industry 4.0	General idea and function
Internet of Things	• Connected network of machines, products and/or humans • Multidirectional communication within the network • Connection via RFID-technology *Example: Smart city applications like smart parking zones, energy management or environmental monitoring*
Big Data	• Storage, collection, and analysis of complex, variable, and large amounts of data • Real-time decision-making support and optimization *Example: Personalized marketing via social media*
Cloud Computing	• Management of big data in open systems • Real-time exchange and communication • Cloud manufacturing as a new manufacturing paradigm for knowledge creation *Example: Cloud storage providers*
Simulation	• Simulation of value chains, business systems or logistics • Optimization and decision-making based on real time data *Example: Virtual traffic simulation or test driving*
Augmented Reality	• Combine and align real and virtual objects • Display of supporting information and interactive learning *Example: AR glasses in warehouse management*
Additive Manufacturing	• 3D & 4D-printing, bioprinting • Decentralized 3D facilities to reduce transport distances *Example: 3D print in healthcare like prosthetics*
Horizontal and Vertical System Integration	• Horizontal: Inter-company integration, automated value chain • Vertical: Intra-company, digital integration among the different levels of the company *Example: Collaborative applications in global value chains*
Autonomous Robots	• Autonomous, cooperating industrial robots • Integrated sensors and standardized interfaces *Example: Drones for last-mile delivery*
Cybersecurity	• Networking between machines, products, and systems *Example: New security applications for complex data sharing*

2. Methodology

The paper follows the approach of a systematic literature review based on five steps defined by Denyer & Tranfield, 2009, see Fig. 1). The aim of this approach is to sharpen the specific methodology of a literature review and provide instructions for locating and selecting existing studies, analyzing and synthesizing the data, and ultimately identifying a clear conclusion about the current strands of research (Denyer & Tranfield, 2009; Tranfield, Denyer, & Smart, 2003). This guideline presents a holistic framework of the whole literature review process and has established itself methodologically (Abdirad & Krishnan, 2021; Colicchia & Strozzi, 2012). The review focuses on a qualitative analysis of the topic but also includes quantitative and descriptive data about the identified publications for further evaluation. The data set derives from the Web of Science database. Besides the limitation on one database, there is always the risk that the defined research string does not cover some relevant insights or that some papers are simply not accessible, whether by subscription or language barriers. To address these potential limitations, I broadened the perspective on geography-related keywords as well as the thematic boundaries of Industry 4.0 to identify as much related literature as possible.

In the following, I give an overview of the basic methodological steps during this research.

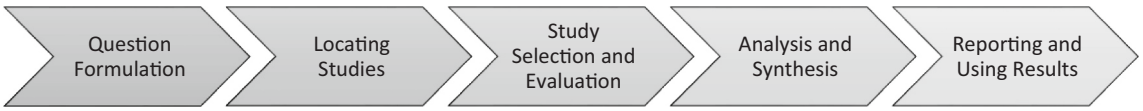

Fig. 1. Steps for a Systematic Literature Review, based on Denyer & Tranfield, 2009.

2.1. Research steps

Step 1: Question Formulation

First, the author gains an overview of the general research trends and the number of publications on the topics. Based on these first impressions, the following research questions guide through the next step of the analysis.

Question 1: What are the current linkages between economic geography and the research regarding Industry 4.0?

Analysis Criteria: Abstract, number of publications, field of research, keywords, research methods, type of study.

Question 2: What are the current research strands and gaps regarding the spatial implications of Industry 4.0?

Analysis Criteria: Theoretical and empirical conclusions of the identified papers and their spatial implications.

Step 2: Locating Studies

Based on the first analysis criteria, the author sharpens its review focus by locating and selecting specific fields of research. The period for the literature review was set between the 1st of January 2011 and the 5th of December 2021 because the debate on the socio-technical aspects of the fourth industrial revolution is still new and key terms like "Industry 4.0" did not exist before 2011. "Industry 4.0" has become the primary synonym when referring to the fourth industrial revolution (Liao, Deschamps, Loures, & Ramos, 2017; Piccarozzi, Aquilani, & Gatti, 2018) and functions as the focal point during this review process. To broaden the perspective on the spatial implications of Industry 4.0, it was necessary to put an emphasis on related keywords, equivalents, and disciplines of economic geography. In particular, keywords like "regional" or "spatial" were crucial to identify potential papers. However, I applied strict exclusion criteria during the further selection process (see Step 3). Table 2 presents the keywords of this systematic literature review. The first screening includes all papers identified with these keywords.

Step 3: Study Selection and Evaluation

Fig. 2 provides an overview of the systematic literature review. The first identification process identified a total of 3190 papers. The deliberately broad selection of keywords thus resulted in a high number of papers. Therefore, the first exclusion focused on their thematic categorization and discipline. I excluded papers with topics referring to non-social sciences like technical engineering or computer science. After the first exclusion, the total results dropped to 548 papers.

After the selection of the relevant papers from the first research results, the author reviews the content of all the remaining papers and evaluates them alongside the aim of the research question. Therefore, the respective research articles must fulfil certain criteria to become part of the subsequent analysis. Table 3 provides an overview of the inclusion and exclusion criteria of the selection process.

The next exclusion selected the papers based on their title, keywords, and abstract. The full-text analysis included 219 papers. After the final review step, the analysis and content evaluation included 177 papers.

Table 2
Keyword strings included in the literature review.

	First part of research string	Second part of research string
Keywords	Regional, spatial, value chain, socio technical system, agglomeration, path development, cluster, innovation system, transition, geographic, geography	Industry 4.0

Step 4: Analysis and Synthesis

The final step of the analysis summarizes the qualitative aspects of the papers and clusters the papers based on their content, type of study and field of research. In the next two chapters, I summarize the results of the descriptive analysis and provide a content analysis of the identified papers.

Step 5: Reporting and Using Results

Finally, the author concludes the main aspects and limitations of the literature review and identifies potential research gaps and new research avenues.

2.2. Descriptive analysis

In the following, I review the descriptive data of the identified papers based on their publication date, journals, research area, and empirical focus. The presentation of the descriptive statistics should give a basic overview and provide some initial analytical insights into the current state of research.

Debates about the socio-technical effects of the fourth industrial revolution are still young and have only recently been intensified in the social sciences. However, the extent of the distribution to date remains surprising (see Fig. 3). 89% of the papers were published between 2019 and 2021 alone.

Table 4 highlights the most represented journals within the identified papers. All in all, the publications spread over many journals. Three journals occurred ten times or more, all the others five times or less. Based on the Web of Science categories, 18% of the papers highlight geography as a main topic, with business economics and public administration being the most frequent topics. As expected during the preliminary work and the review process, most studies on spatial implications of Industry 4.0 are part of related disciplines rather than economic geography itself.

In terms of empirical approaches, most studies apply Industry 4.0 research to the manufacturing sector as a whole. More explicit sectoral research is rare. Some studies involve a focus on transport, mobility, or logistics (Baştuğ, Arabelen, Vural, & Deveci, 2020; Pham et al., 2019), construction (Dallasega, Rauch, & Linder, 2018; Lekan, Aigbavboa, Babatunde, Olabosipo, & Christiana, 2020), or food and agriculture (Ali & Aboelmaged, 2021; Klerkx, Jakku, & Labarthe, 2019; Oltra-Mestre, Hargaden, Coughlan, & Segura-García del Río, 2020). Other examples remain individual cases, like aviation (Götz, 2019a), electronics (Kahle, Marcon, Ghezzi, & Frank, 2020), steel (Martins, Paula, & Botelho, 2021), ceramic tile (Hervas-Oliver, Estelles-Miguel, Mallol-Gasch, & Boix-Palomero, 2019), oil (Mutanov, Zhuparova, & Zhaisanova, 2020) or furniture/woodworking (Pagano, Carloni, Galvani, & Bocconcelli, 2020). Concluding, most empirical perspectives on spatial implications of Industry 4.0 to date are very broadly defined and lack sector-specific case studies and contextuality. Gaining deeper insights into sectoral characteristics is important to understand the geography of innovation and potential inequalities between different sectors, regions, and labor forces.

3. Results

In the following, I analyze the papers based on their analytical contributions to the spatial implications of Industry 4.0. Therefore, I categorize the identified papers and grouped them according to their thematic focus. Five central classifications became apparent. Table 5 provides an overview of the main topics and their spatial implications. It

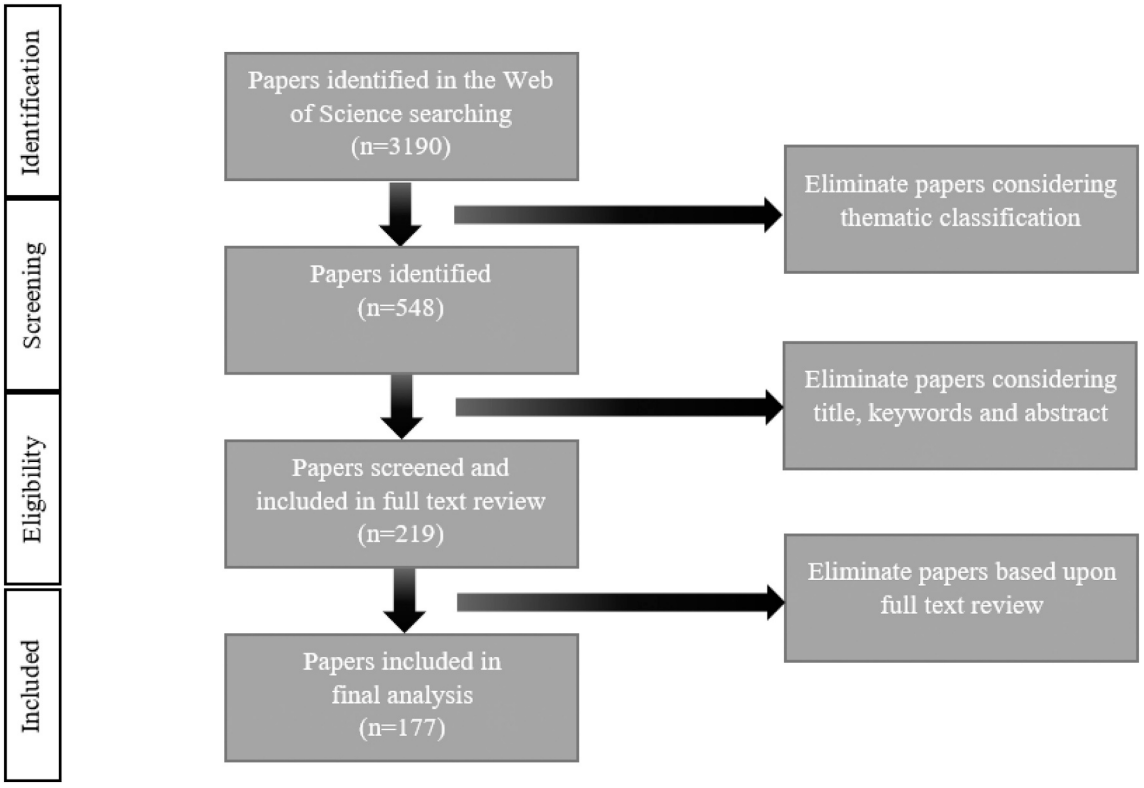

Fig. 2. Overview of the systematic literature review, period 1st of January 2011 – 5th of December 2021.

Table 3
Inclusion and exclusion criteria.

	Criteria	Criteria Explanation
Exclusion	Language	A paper is not in English in its full text.
	Non-related "Industry 4.0"	Industry 4.0 is only used as a buzzword without being the analytical focus of the paper. The paper focusses on non-social sciences aspects of Industry 4.0
	Non-related "geography"	The paper analyzes or reviews topics without spatial implications or specific geographical dimension.
Inclusion	Closely related	The research has an explicit focus on economic geography or spatial developments in the context of Industry 4.0.
	Partially related	Papers from closely related research fields that discuss a spatial implication of Industry 4.0

is evident that Industry 4.0 as a research field is primarily considered in existing conceptual approaches such as clusters or innovation ecosystems. In addition, key debates about the fourth industrial revolution comprise the impact on the labor market or readiness factors for the successful adaptation of regional industries. However, theoretical links and holistic approaches that put an emphasis on socio-technical effects of Industry 4.0 from a spatial perspective are still rare.

3.1. Value chains and supply networks

One of the most thriving research fields concerning Industry 4.0 is the restructuring of value chains. The spatial transformation of supply chains at different scales not only reshapes production networks but also transforms existing structures through radical innovations.

Industry 4.0 encompasses several dimensions of industrial value creation: a high-grade digitization of processes, smart manufacturing, and inter-company connectivity (Müller et al., 2018). Therefore, the transformation also addresses different dimensions of proximity, such as technological, organizational, geographical, or cognitive proximity (Dallasega et al., 2018). New digital technologies disrupt the location and organization of activities within global value chains (GVC) and who captures the actual added value (Strange & Zucchella, 2017). A key word used in the context of value chain formation during Industry 4.0 is the aspect of “backshoring” or “reshoring” activities. This describes the process in which parts of a value chain that were formerly outsourced return to their original location using new technologies. This allows companies to produce and manage both physical objects (3D-printing) and digital data (cloud computing) regardless of their location. Drawing from a dataset of 1700 manufacturing firms from Austria, Germany, and Switzerland, Dachs et al. (2019) state that backshoring is still a rare event that was only observed in 4% of the firms. However, there is a positive correlation between the adoption of Industry 4.0 technologies and backshoring propensity (Dachs et al., 2019). Ancarani et al. (2019) find that backshoring initiatives that aim at the reduction of direct costs or responsiveness are not significantly tied to Industry 4.0 adoption. Kamp and Gibaja (2021) highlight that the correlation between Industry 4.0 and backshoring is uncertain and that other local-specific factors have a greater impact on the decision making of relocating activities. Thus far, there is only weak empirical evidence on how Industry 4.0 influences backshoring activities and what sectors or labor forces are primarily targeted by these changes. Besides the reformation of the inter-company supply chains, consumer behavior changes as well. Drawing from insights on the food industry in Germany, Oeser et al. (2018) expect services like home-delivery as well as decentralization and regionalization to gain importance. Smart logistics in the context of Industry 4.0 are important to facilitate an efficient and effective food

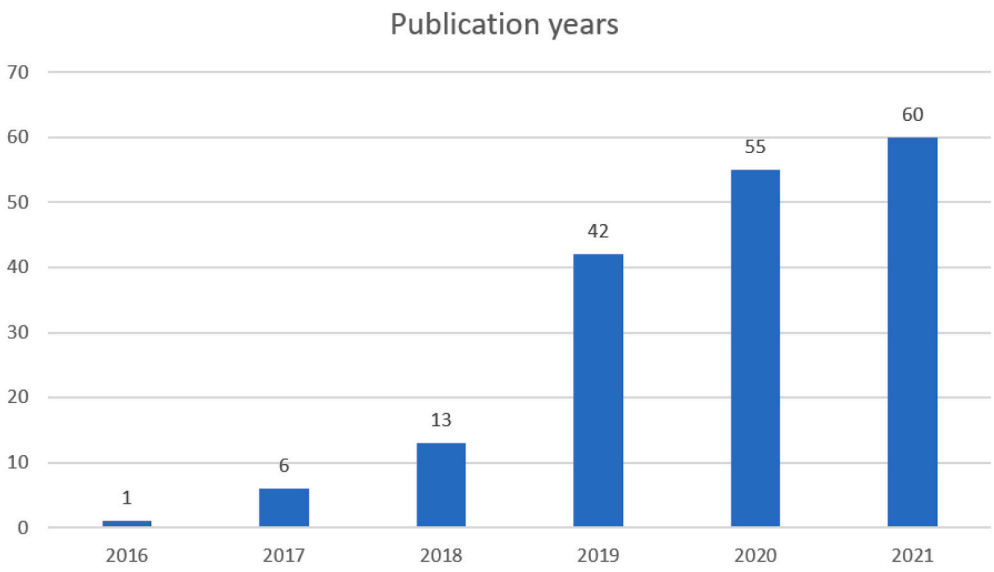

Fig. 3. Publication years (Based on Web of Science, 5th of December 2021).

Table 4
Journals with more than ten publications.

Name of the journal	Number of Papers
Regional Studies	11
Technological Forecasting and Social Change	11
European Planning Studies	10

supply (Oeser et al., 2018). There is also a growing interest in how Industry 4.0 can enable circular or sharing economies (Jabbour et al., 2020; Tham & Ogulin, 2021; Yu, Khan, & Umar, 2021). Thus, Industry 4.0 interacts with other megatrends such as urbanization, sustainability, or existing spatial inequalities. There is a risk that Industry 4.0 could also act as a multiplier for global development gaps within and between countries (Primi & Toselli, 2020).

Despite still being in its infancy, Industry 4.0 already has effects on the nature of competition and corporate strategies in many industries (Strange & Zucchella, 2017). However, there is no clear understanding of how value chains are influenced and what spatial implications occur during this restructuring. Geographers should put an emphasis on the different dimensions of spatial inequality but also approach the issue from a more qualitative perspective to gain insights into the actual motivations and causalities of new supply networks.

3.2. Clusters and industrial districts

Clusters became a prominent research field in economic geography during the 1990s and 2000s. However, the topic emerged in neighbored disciplines, and it took some time for geographers to position themselves in the research (Martin & Sunley, 2001). The impact of Industry 4.0 on the emergence, evolution, and restructuring of clusters provides a promising research avenue for future studies.

By forming a "culture of cooperation", clusters can ensure smooth digital business transformation and enforce innovation developments at a local scale, therefore strengthening the adaptability of companies (Götz, 2019b). However, due to technological and socio-economic restructuring, Industry 4.0 has a major impact on the formation of clusters. The complexity of the fourth industrial revolution requires a combination of traditional mechanisms and innovative developments (Pagano et al., 2020). Clusters can provide several benefits for the adaptation of regional industries. Götz (2019a, 2020) draws on case studies from Germany and the potential benefits that clusters can provide for adopting Industry 4.0 developments. The presence of key actors and networking structures provide a form of "(un) articulated proximity", that can counteract the uncertainty and disruptive elements of Industry 4.0 (Götz, 2019a). Besides, they provide a knowledge environment and organize policymaking in a specific area (Götz, 2020). However, these positive effects of clusters and their cooperation networks are so far only observed in highly developed industrialized nations and mostly in high-tech industries. Some studies put an emphasis on the impact of Industry 4.0 on industrial districts, primarily in Italy. Bettiol et al. (2020) highlight that there are differences between district and non-district firms in terms of Industry 4.0 investments, the motivation for adoption, and the results achieved. Manufacturers within industrial districts tend to have higher investment rates in technologies like big data, cloud management, augmented reality, and primarily aim for product diversification. Therefore, Industry 4.0 rather emphasizes the peculiarities and competitiveness factors typical of the district model instead of leading to a disruptive breakthrough (Bettiol et al., 2020). Pagano et al. (2020) observe a more diffuse development and recombination within industrial districts in Italy. As new players, activities and resources emerge, the upgrading processes, initiatives and projects by firms and institutions in the context of Industry 4.0 become more fragmented. In their case study, existing sectoral or geographical boundaries become increasingly blurred (Pagano et al., 2020). Hervas-Oliver et al. (2019) highlight the positive leverage of isomorphism in industrial districts, as collective actors and forerunners are crucial to engage in the transition toward Industry 4.0.

Despite the research being limited to a few studies and geographical locations, it becomes clear that Industry 4.0 has a measurable effect on clusters and industrial districts even in the early stages of technological development. These developments challenge both the micro and macro scale of cluster formation, as new key actors, knowledge networks, and companies become increasingly important for a successful transition. Therefore, not all clusters will benefit from the ongoing digital transformation. Only those with an adequate knowledge base and expertise in 4.0 technologies can contribute to the development of the fourth industrial revolution (Götz & Jankowska, 2017).

3.3. Readiness and adaptation of regional industries

Several studies try to identify potential measurable factors for evaluating the readiness and adaptation potential of regional industries in the context of Industry 4.0. There is a strong focus on quantitative approaches to understand regional characteristics for the integration of

Table 5
Main topics of the identified research.

Themes	Examples	Spatial implications
Value Chains and supply networks	Kamp & Gibaja, 2021; Schmidt, Veile, Müller, & Voigt, 2020; Ancarani, Di Mauro, & Mascali, 2019; Dachs, Kinkel, & Jäger, 2019; Pham et al., 2019; Tortorella, Giglio, & Van Dun, 2019; Barbieri, Ciabuschi, Fratocchi, & Vignoli, 2018; Müller, Buliga, & Voigt, 2018	• I4.0 changes supply chains and logistics fundamentally • Correlation of backshoring and relocating activities with adoption of I4.0 is in an open debate • Strong supply chains and absorptive capacity can enforce I4.0 adoption • I4.0 as a driver for implementing circular economy
Clusters and industrial districts	Bettiol, Capestro, De Marchi, Di Maria, & Sedita, 2020; Grashof, Kopka, Wessendorf, & Fornahl, 2020; Pagano et al., 2020; Götz, 2019a, 2019b; Jasinska & Jasinski, 2019; Batz, Kunath, & Winkler, 2018; Götz & Jankowska, 2017	• Clusters provide potential for knowledge spillovers, intra- and inter-business processes and organize policymaking • Proximity supports networking in terms of I4.0 • Adoption of I4.0 creates new key actors, routines and paths that reshape the structural embedding of clusters as well as sectoral connections and geographical locations • Success depends on the knowledge base and expertise for IT solutions, some clusters and industrial districts may be left behind in the development
Readiness and adaptation of regional industries	Balland & Boschma, 2021; De Propris & Bailey, 2021; Laffi & Boschma, 2021; Fuchs, 2020; Haefner & Sternberg, 2020; Agostini & Filippini, 2019; Pini, 2019	• Regional disparities in terms of readiness and adaptation factors can be observed on different scales • New capital agglomeration unfolds in the context of smart manufacturing • I4.0 can potentially create new or intensify existing spatial inequalities
Innovation development and ecosystems	Adler & Florida, 2021; Barzotto, Corradini, Fai, Labory, & Tomlinson, 2020; Dressler & Paunovic, 2020; Habraken & Bondarouk, 2020; Kahle et al., 2020; Lepore & Spigarelli, 2020; Danubianu, Teodorescu, & Corneanu, 2019; Matthyssens, 2019; Szalavetz, 2019; Shin, 2017	• Path-breaking disruptive and open innovations create new markets and external collaborations • Verifying opportunities and benefits of I4.0 is highly relevant due to the impacts and risks for regional economy • Technology deployment can automate tacit knowledge-intensive activities and at the same time create new spaces for knowledge creation • Policy directions, like Smart Specialization, need to be adjusted to cope with I4.0 developments
Labor market	Anshari, Almunawar, & Razzaq, 2021; Malik, Tripathi, Kar, & Gupta, 2021; Hat & Stoeglehner, 2020; Rainnie & Dean, 2020; Liboni, Cezarino, Jabbour, Oliveira, & Stefanelli, 2019; Hirsch-Kreinsen, 2016	• The volume of potential job losses or regional diversities caused by I4.0 is still highly controversial • Upgrading, substitution and/or polarization of skills • Some studies show no clear spatial structures or localities of risks or resilience regarding I4.0

Industry 4.0 developments.

Industry 4.0 can impact national and regional comparative advantages in terms of key enabling technologies. However, we know very little about this economic phenomenon (Ciffolilli & Muscio, 2018). Governments play a crucial role in creating an interactive environment for Industry 4.0 (Poma, Shawwa, & Maini, 2020). There is a diversity of potential adoption drivers for Industry 4.0, as both internal and external resources are crucial (Habraken & Bondarouk, 2020). Nhamo, Nhemachena, and Nhamo (2020) analyze ICT indicators to measure the readiness of countries to implement Industry 4.0 and the Smart Development Goals. There is a massive divide between the Global North and Global South. While the top ten countries rank between 71 and 78 points (out of 100, rounded), the bottom ten countries rank between 0 and 6 points. All these bottom-ten countries are African, with Sub-Saharan Africa being the weakest region on a global scale. The European Union appears to be the strongest region (Nhamo et al., 2020). Laffi and Boschma (2021) indicate that Industry 4.0 adoption in Europe is primarily tied to regions with a strong knowledge base in Industry 3.0 technologies, but there is also some diversification in regions with other knowledge bases. However, most regions show weak Industry 4.0 potential, which strengthens the assumption that the benefits focus on certain industrial centers (Balland & Boschma, 2021). As these findings correlate with the general European-centric characteristics of the Industry 4.0 debate, the risks of additional spatial inequalities in terms of development goals become clear. Other authors also highlight spatial inequalities on a regional level. Pini (2019) investigates family management and Industry 4.0 in Italy. The findings show that external management in the more economically strong north affects the propensity for innovation significantly, while firms in the structurally weaker south require simultaneous investment in research and development (Pini, 2019). Drawing on a quantitative study of manufacturing firms in Slovenia, there is a positive link between Industry 4.0 investments and export performance (Naglič, Tominc, & Logožar, 2020). Nick, Várgedő, Nagy, and Szaller (2019) analyze the regional economic effects of Industry 4.0 in Hungary with survey data from a diverse set of manufacturing firms. They highlight sectoral differences as the main element for regional differences. However, there is a general unsatisfaction with the competence of the labor force and a big gap between the expectations of Industry 4.0 and the actual technological advancements. Those negative findings tend to be even stronger in peripheral regions (Nick et al., 2019). Other authors highlight the shortcoming of reducing spatial disparities by Industry 4.0 as well, stating that there is little or no shift between industrial centers and peripheral regions in Germany so far (Greef & Schroeder, 2021).

The analysis of regional readiness and adaptation appears to be one of the most thriving topics with spatial implications. However, the debate is so far based on conceptual and quantitative approaches with a lack of qualitative insights. Another question is whether Industry 4.0 works as a multiplier or counteractor of existing spatial disparities or creates new inequalities. The complexity of regional development raises a lot of potential future research questions, like the interplay of sectoral and geographical differences or the gap between rural and urban areas.

3.4. Innovation development and ecosystems

Industry 4.0 includes several innovative developments that reshape not only technological paradigms but also the economic and social landscape. Tackling these socio-technical advancements from a spatial perspective is crucial for the adjustment of innovation policies and the impact on innovation systems.

To date, key factors for regional innovation policies to facilitate Industry 4.0 or create new path developments remain an understudied topic (Hervas-Oliver et al., 2020). Some authors highlight the challenges and policy directions for Smart Specialization to deliver better regional cohesion, inclusive growth, and tackle the outcomes of Industry 4.0 (Barzotto et al., 2020; Lepore & Spigarelli, 2020). Klincewicz (2019) reviews the patenting activities in the context of Industry 4.0 in Poland. He reveals gaps in the adoption and development of robotics, the

marginal popularity of the field, and the limited inflow of locally developed and innovative solutions. Thus, only a few companies engage in patenting activities. However, the unsatisfactory progress toward Industry 4.0 might create windows of opportunity in the near future (Klincewicz, 2019). Research on innovation policies and their spatial implications for Industry 4.0 is still a very conceptual research field with few empirical indications. Other studies put a stronger emphasis on technological developments and specific innovations. Some authors discuss policy strategies of IoT adoption and potential benefits for environmental or social aspects on different scales (Danubianu et al., 2019; Shin, 2017). Szalavetz (2019) analyzes the impact of advanced manufacturing technologies on production capability in a case study in Hungary. The author concludes that the new technologies fundamentally redefine the boundaries of production activities. While the transformation automated some knowledge-intensive technological activities, other local technological activities became more knowledge-intensive (Szalavetz, 2019). The insights support the assumption that innovations and the acquired skills in the context of 4.0 restructure knowledge networks and create new path developments while other established structures become obsolete. Besides industrial embedding, Industry 4.0 also creates new spaces for innovation developments, such as urban tech, which is strongly associated with the smart city debate. These technologies cluster primarily in specialized regions or large cities and are strongly dependent on the innovation capabilities of the metropolitan areas (Adler & Florida, 2021).

Concluding, studies on the geography of innovation in the context of Industry 4.0 remain strongly on the micro scale, dealing with business models or key technology developments. There is a lack of studies conducted on aspects like spillovers, institutional settings, or the geography of transitions. Moreover, it is important to identify and formulate new policy implications to adjust current frameworks for a smooth transition process.

3.5. Labor market

The debate about the restructuring of the labor market and the future of employment is one of the most prominent and ongoing debates associated with Industry 4.0 (Frey & Osborne, 2017; Zuboff, 1988). Aside from the general discussion of how the working world transforms during the fourth industrial revolution, it is critical to consider the sectoral and regional specifications of the labor market transformation to gain deeper insights on the spatial differences.

Regional diversities of innovations and skills are a key aspect that matters in workforce changes and requirements for approaching Industry 4.0 (Vassiliadis & Hilpert, 2020). Dominant themes of the topic are educational changes, new employment scenarios, work infrastructure resources, and work meaning and proposal (Liboni et al., 2019). However, several authors discuss the distribution of these changes controversially. They recognize upgrading and polarization of skills, job activities, and qualifications. There are numerous factors that influence the extent of these processes (Hirsch-Kreinsen, 2016). The discussion is highly conceptual, with empirical insights still lacking. There is also a dominant role of developed countries in terms of research production (Liboni et al., 2019). Hat and Stoeglehner (2020) analyze the spatial context of the susceptibility of regional labor markets to Industry 4.0 in Austria. They find that digitalization risks show no clear spatial patterns so far. However, urban areas or small towns tend to be less exposed to job losses than rural areas. There is a need to put an emphasis on aspects like regional resilience and social vulnerability to gain a better understanding of spatial inequality in the context of Industry 4.0 (Hat & Stoeglehner, 2020). Other studies contend that Industry 4.0 enforces "platform capitalism", which is so far primarily impactful in the Global South but can potentially also influence the work quality in the Global North as a result of the digital transformation (Rainnie & Dean, 2020). Besides the regional impact, the integration of Industry 4.0 technologies strongly affects the actual working space of employees. Therefore, they require supportive practices for these evolving socio-technical relationships (Malik et al., 2021). Moreover, the educational system for Industry 4.0 related activities must adapt and consider the specific job characteristics, like the level of routinization or emotional dimensions (Anshari et al., 2021).

As of right now and due to the early development of Industry 4.0 and associated technologies, only few empirical insights on the spatial distribution of future workforce exist. However, the labor transformation can potentially have the strongest impact on social inequalities if policies fail to develop adequate countermeasures.

4. Discussion

Based on the preceding analyses, there is an underrepresentation of economic geography in Industry 4.0 research to date. Neighboring disciplines account for a large part of the research. However, spatial implications and interactions are the exception as well and often only a partial aspect of the discussion. Moreover, there is a lack of qualitative and especially exploratory studies to uncover the spatial developments of Industry 4.0 and identify specific peculiarities. The vast majority of case studies think of Industry 4.0 development in a spatial-narrowed sense, primarily from the perspective of a single firm, quantitative data, or single value chains. Spatial understanding often remains within a "container"-perspective and neglects the complexity of these socio-technical developments. This perspective runs the risk of not understanding how Industry 4.0 can also reshape current spatial boundaries, policies, and regional industries.

Therefore, we need to strengthen the understanding of Industry 4.0 as a multi-scalar development that influences several geographical dimensions. This chapter should give an idea of how a broader perspective can bridge the different conceptual and empirical phenomena of Industry 4.0. I highlight linkages between the different research strands with an emphasis on the micro and macro scale of these developments. As in all debates regarding scales, we cannot describe all phenomena as solely local or global ones as they are often intertwined on a *meso* scale. However, this discussion should give an idea of how future research can tackle the lack of spatial implications for Industry 4.0. Based on these insights, I highlight potential research avenues for economic geographers and how a spatial focus can enrich the research on Industry 4.0 and thus contribute to the wider discussion of digital geographies.

Industry 4.0 creates new time and space specific opportunities for both industrial and societal progression. These so-called windows of opportunity (Döringer, 2020) link innovation development with the restructuring of value chains and the potential for clusters and regional industries. On the macro scale, these linkages call for research on knowledge networks as well as the absorptive capacities of a region or cluster to successfully embed these new technologies from a structural perspective. Besides, technological characteristics and their impact on path creation have only been insufficiently investigated (Njøs et al., 2020). On the micro scale, this affects the actions of all stakeholders embedded in these developments, as they feel compelled to create new policies and agendas toward a successful transformation. Therefore, an embedded and reflexive agency implies the necessity of combining different skills and creating opportunities for structural change. We can divide so-called opportunity spaces into time-, region- and agent-specific. They bridge the agent level with the structural level of change. Thus, actors are embedded in an opportunity space that is specific to a region, industry, time, and limited access to knowledge, resources, regional preconditions, and capabilities (Grillitsch & Sotarauta, 2020).

A common buzzword in this context is the narrative about the smart city of the future (Cocchia, 2014). However, as the smart city has become a frequent political term outside of its academic context, a critical debate about the actual definition of smart innovations and their benefits for society and sustainability is crucial, as they can also hinder societal development or only act as greenwashing elements in urban

planning (Bibri & Krogstie, 2017). Besides radical technological innovations, new processes like platform urbanism and platform cooperatives (Chiappini & de Vries, 2021; Rose, 2021) or social innovations (Jurenka, Cagáňová, Horňáková, & Stareček, 2019) can emerge through the lens of smart urban development. There is also a growing interest in differentiating between corporate driven smart cities and grassroot initiatives (Lynch, 2020).

Despite some digital technologies being still in their infancy and not being part of a wider socio-technical embedding yet, they highly influence market structures and create additional niche developments. One example here is the development of urban air mobility, like drones for logistics or air-taxis for passenger transport. Even though these technologies do not exist so far on a larger scale due to a lack of infrastructure and legal framework for the urban air space, drone development has created a vast number of startups and venture capital over the years because of the expectation that they will be part of our everyday lives sooner or later (Reiche et al., 2018). These beliefs and expectations do not only create a healthy environment for experimentation and testing grounds, but also run the risk of an early lock-in in path creation.

Therefore, knowledge creation through the digital and digitally mediated knowledge can impact geographies in several aspects (Ash et al., 2018). Considering big data and the internet of things, it becomes easier to access information spatially via cloud computing and generate data in real-time by connecting digital and physical elements. Such technologies are increasingly being used in different use cases, such as traffic management in urban areas to increase the transparency of city logistics and address safety issues in contested spaces (Fraske & Bienzeisler, 2020). Thus, human interactions, skills, and (in)formal institutions are also being restructured by these new knowledge flows. Empirically, this aspect raises the question of how these knowledge flows unfold in a spatial sense. Despite the often-generalized assumption that globalization and digitalization lead to a lower importance of local embeddedness, phenomena like Silicon Valley prove that even in contrast to these global developments, local knowledge networks remain one of the most crucial factors for regional industries. However, it remains unclear whether digital technologies create their own clustered environments, or if they are more likely to transcend existing industries and organize in entrepreneurial ecosystems (Spigel & Harrison, 2018). Due to the complex structures and the high amount of venture capital in these developments, regional development needs to address long-term risks to avoid sunk costs like in the last industrial revolutions.

Moreover, new spatial settings produce "geographies by the digital", which refers to the production of space and the transformation of socio-spatial relationships (Ash et al., 2018). This concerns aspects of the infrastructural linkages in the context of cyber-physical systems and the embedding of digital technologies in existing socio-technical systems. Furthermore, it raises an even larger and overlaying debate about how the fourth industrial revolution changes our understanding of space, scalability, and proximity. As our understanding of the fourth industrial revolution is primarily shaped by developments in highly developed countries and regions, a stronger focus on lagging regions like rural areas with a weaker policy environment and a lack of investment can enrich the debate as well.

One promising and interdisciplinary research avenue in this context is the thriving discussion about the geography of transitions. Despite the growing interest in geography in this research area, digital innovations have only marginally been investigated. The debate about the geography of transitions evolved out of the established research on sustainability transitions (Hansen & Coenen, 2015). The research primarily focuses on the spatial dimension of socio-technical systems and sustainability developments and thus the geographical diffusion of innovations. A place-based perspective can enrich the existing conceptual approaches and highlight the importance of Industry 4.0 specific path development (De Propris & Bailey, 2021). We should not view the disruptive developments of Industry 4.0 from a primarily techno-centric perspective but strongly consider the spatial dimensions of society and sustainability as well. This aspect addresses the need for more empirical research on the role of intermediaries and urban policy in accelerating Industry 4.0 as well as on the geography of innovation and the geography of entrepreneurship (Haefner & Sternberg, 2020). A deeper understanding of these issues can offer linkages between research on technological development, geography, and sustainability transitions. This accounts for established frameworks like the multi-level-perspective (Geels, 2002, 2020) for a better understanding of niche, regime, and landscape developments during Industry 4.0 as well as for more specific topics like regional diversification and specialization (Boschma, Coenen, Frenken, & Truffer, 2017). Addressing these developments from a transition studies perspective can provide empirically grounded research on spatial inequalities and strengthen the view on sectoral or geographical differences, like the social acceptance of Industry 4.0. However, there is an underrepresentation of categories like space, scale, and the spatial understanding of niches and regimes which offers the potential for a more thought-out contribution to this topic.

Besides its infrastructural impact, cyber-space itself creates "geographies of the digital", such as on social media or online games (Ash et al., 2018). In the context of Industry 4.0, this includes digital platforms for controlling new technologies, which also address data protection issues. Long-term effects like the upgrading of artificial intelligence or augmented reality offer further research avenues. For example, innovations based on augmented reality challenge the way people perceive space, such as location-based app games (Birtchnell, McGuirk, Moore, & Vettoretto, 2020). Industry 4.0 innovations are a good example of how physical and digital infrastructures can overlap, while at the same time, this connection can form new processes for knowledge creation and cyber-spaces in which originally physical objects exist as "digital twins." This approach is already frequently used in urban planning and enforces a new paradigm regarding planning practices. In an industrial sense, it also provides additional opportunities regarding the real-time creation and adaptation of goods and processes, like in health care. How is data aggregated and used in a spatial sense? And how dependent is cyber-space on certain economic sectors and vice versa?

At the interface of all these developments stands, again, the restructuring of the labor market. However, instead of focusing on the predominantly widespread debate about the future of work on a macro scale, it could be more promising for geographers to highlight the measurable effects of the digital on actual working practices. As new business models establish due to the use and emergence of new digital innovations that ultimately create new forms of value but also precautious job markets, like the gig economy (Vallas & Schor, 2020). Accelerated by the Covid-19 pandemic, the deterritorialization of work is another important spatial observation, especially in the service sector. Moreover, the creation of cyberspace is a fitting example regarding the question of whether digital technologies create radically new processes or just recreate or reinvent existing practices. As the job market is already organized primarily with digital platforms or social networks like LinkedIn, it could be argued that application processes and hiring are highly influenced by the digital. However, the impact of this digital influence on persistent problems regarding accessibility or equal opportunities in labor markets remains open for debate as well. Do these platforms provide new opportunities for so far marginalized social milieus, or are they just a new form of established competition? Therefore, the spatial distribution of labor and work practices offers a broad range of potential avenues for geographers.

Table 6 summarizes the results of this article. These findings and research avenues are by no means exhaustive, but they should offer a starting point for theoretical engagement and new empirical research on the emerging and thriving debate about digital geographies.

Table 6
Summary of thematic insights and research avenues.

Category	Linkages between the topics on the micro/macro scale	Research Avenues for digital geographies of Industry 4.0
Value chains and supply networks	**Micro:** Disruptive impact on local production, labor, and sustainability agendas; creation of entirely digital work practices.	What potentials or risks lie in the restructuring of value chains by the digital for tackling global inequality and sustainability transitions?
	Macro: Clusters and regional industries must adapt to the new economic and institutional settings of GVCs.	How does the reshoring of GVCs impact local labor markets?
Clusters and industrial districts	**Micro:** Local knowledge base and agency influenced and mediated by the digital.	Do digital innovations preferably evolve in clusters or entrepreneur ecosystems?
	Macro: Impact on the production of digital technologies and creation of new sectoral linkages and interdependencies.	How do digital technologies transcend existing sectors? How does the digital influence the importance of local and global ties for firms and clusters?
Readiness and adaptation of regional industries	**Micro**: Importance of a supportive policy for mediating digital practices and working routines.	How can an efficient change agency enforce path creation?
	Macro: Regional diversification and adaptation is accelerated by digital innovations.	How do industries create regional resilience toward Industry 4.0? (Societal, environmental, economic)
Innovation development and ecosystems	**Micro:** New policies and urban agendas create experimental space for new ideas.	How can public actors successfully integrate long-term planning strategies?
	Macro: Restructuring of socio-technical regimes; existing regions and sectors offer different prerequisites regarding their innovation capacity.	How does a geographical perspective enrich the view on socio-technical development? How do new windows of opportunities evolve out of the digital transformation?
Labor market	**Micro:** New agency patterns, platforms, and deterritorialization of work practices; new business models.	How do digital innovations affect spatial boundaries of labor and work routines? How can these innovations contribute to a more acceptable and sustainable work environment?
	Macro: Restructuring of regional labor markets, establishment of new forms of labor and digital platforms.	How do cyber-space and digital applications affect the distribution of labor?

5. Conclusion

The main objective of this systematic literature review is to provide insights into the current state of research on the geographical dimensions of the fourth industrial revolution. The author applies appropriate inclusion and exclusion criteria to identify papers that match the intention and research question regarding the spatial implications of Industry 4.0. The review of academic publications from the database Web of Science identified 177 papers that are included in the final analysis. While research on this issue becomes more dispersed in terms of empirical and theoretical embedding, there has yet to evolve a comprehensive understanding and differentiation of the research strands and interdisciplinary approaches. The content analysis reveals five main research areas that current articles focus on: Value chains and supply networks, clusters and industrial districts, readiness and adaptation of regional industries, innovation development and ecosystems, and labor market. Based on these insights, I propose a comprehensive discussion of the interlinkages and research avenues for digital geographies.

In conclusion, research on the different geographies of Industry 4.0 offers a thriving but understudied issue that connects several aspects of the debate around digital geographies and their impact on society. Complementary to a techno-centric or business-oriented understanding of the fourth industrial revolution, geography should play a central role in the academic debate as Industry 4.0 renegotiates spatial relations on different scales and can create new spatial inequalities as well as unfold new potential for regional development.

Declaration of interests

The author declares that he has no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Toward smart and sustainable traffic solutions: a case study of the geography of transitions in urban logistics

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ABSTRACT

City logistics as a research field offers a wide range of potential solutions and technologies for advancing toward modern and sustainable mobility. As societies demand environments that are more ecological and cities tackle the effects of growing e-commerce, innovative tools to regulate urban economic traffic become increasingly important. Based on the theoretical approach of the multi-level perspective, this case study combines findings from city-logistics research with evolutionary economics to gain a deeper understanding of the development of smart sustainable cities. The study strengthens the view on the geography of a transition with a focus on the interplay of changed practices, involved actors, and pathways. The analysis is based on qualitative social research, including interviews with various stakeholders. It examines the implementation of an app-based technology to regulate economic transport and delivery traffic in Barcelona. The municipal administration introduced the innovation in the Urban Mobility Plan and quickly integrated it across the city. The commitment of a software developer resulted in an enhanced version of the technology by a startup company. The development of the original innovation thus led to geographic diffusion of the upgraded technology through processing actors' feedback and targeting new markets outside the city.

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Introduction

The transition toward smart and sustainable cities offers a broad set of potential research fields. One of these aspects is the geographic dimension of transitions, concerning the extent to which spatial relationships can influence the emergence and success of socio-technical transitions and how transitions can differ depending on their location (Hansen and Coenen 2015; Köhler et al. 2019). However, the theoretical approaches have yet to overcome a "naïve conceptualization of space, scale, and power" (Truffer and Coenen 2012, 15). Recent frameworks promote a combination of transition studies and evolutionary economic geography, thus referring to the evolutionary economics background of both theoretical fields (Boschma et al. 2017; Fastenrath and Braun 2018a). Several authors have drawn attention to the concern that geographic concepts on transitions need a more practice-oriented research focus and should strengthen the importance of practices that can influence processes like learning, governance, and technology development (Fastenrath and Braun 2018a). In this context, the roles of smart sustainable cities (Bibri 2018, 2019; Thornbush and Golubchikov 2019) and urban transitions are of significant relevance, as cities can be strong promoters of sustainability transitions since they provide crucial resources for successful innovation processes in a socio-spatial context (Truffer and Coenen 2012; Fastenrath and Braun 2018a).

We examine the urban transition of an app-based technology to regulate city logistics in Barcelona. Our approach follows two main research questions: *How can urban policies support the geographic transition of an innovation? And how can the interplay of changed practices, involved actors, and pathways lead to a successful transition?*

To answer these questions, we combine insights from transitions studies and economic geography and focus on enriching the multi-level perspective (MLP) with a geographic perspective. While the MLP is a well-established and commonly used theory in the field of transition studies (Geels 2002, 2011, 2020), the influence of digital innovations on transitions has been only marginally considered (Kompella 2017; Jakku et al. 2019; Köhler et al.

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2019). Moreover, it is important to analyze faster-paced developments that are part of the overlaying transition processes. As sustainability transitions generally refer to long-term and typical green technologies (Binz and Truffer 2017), there is a need to highlight the role of technologies where sustainability is only one out of several possible benefits.

Our conceptual framework consists of three analytical entities and their reciprocal interactions in a socio-spatial context, as presented by Fastenrath and Braun (2018a). First, we highlight the role of pathways, including their technological and political-institutional dimension. Second, it is important to understand the process of changed practices, primarily in the form of learning processes as well as their drivers and barriers. Finally, we call attention to the relevance of individual and collective actors in the process of the transition, regarding both private and public actors.

In our case study, we show that the understanding of these categories in a socio-spatial context is important to appreciate how the innovation transferred from a local niche to multi-geographic regimes.

We argue that learning processes and single pioneers can heavily influence the direction of a socio-spatial pathway. Previous research shows how initial bottom-up paths might become later in the process a dominant top-down path (Fastenrath and Braun 2018b). However, our case study shows that this process also works in the opposite direction. Most important here is the role of so-called transition agents that can strongly promote technological development and its socio-spatial integration (Fastenrath and Braun 2018a). This can lead to geographic diffusion of an innovation in new urban contexts. Our research reflects the development of an innovative solution for smart loading zones and reconstructs the evolutionary development of the app-based technology. The innovation was developed by the municipal administration and later upgraded by one of the original developers in a startup company. We show that the successful transition of a new, but not yet established technology can potentially depend on the ability to access several localized regimes, rather than relying on only one single location. For instance, it is important to transfer the technology out of the original context and policy frameworks and facilitate experimentation in other geographic contexts with different institutional settings.

This article is structured as follows. The next section provides an overview of the current challenges in urban logistics and the role of local policy to address these challenges. We also in this section introduce the case of Barcelona. We then highlight the basic ideas and assumptions of the MLP and the current state of research on the geography of transitions and present the conceptual framework of this case study based on the combination of transition studies and economic geography by Fastenrath and Braun (2018a). We subsequently describe the study's methodological approach and offer a deeper understanding of the development of the innovation in Barcelona, specifying its functionality and sustainability impact. Building on these findings, we analyze the urban transition process based on the conceptual framework. The final section summarizes the key findings of this case study, identifies its limitations, and describes potential future research avenues.

Research field: Current challenges in urban logistics

The following section provides an overview of the current challenges in urban logistics and how innovation and local policy can address these issues. Increased urbanization prompts action on the part of municipal administrations, especially due to the lack of space and the impact of climate change. To master these challenges, cities like Barcelona have been emphasizing the development of smart city and mobility agendas.

Urbanization, sustainability, and digitization as major challenges

The rise of digitization, alongside the effects of urbanization processes and sustainability transitions, will change urbanism in fundamental and irreversible ways. In this context, smart sustainable cities have become a leading global paradigm of urban planning. Urban policies and promising innovations aim to overcome the challenges of sustainability and to contain the effects of urbanization by the increasing use of information and communication technology (ICT) in cities (Bibri 2019; Thornbush and Golubchikov 2019).

The three main technological fields supporting urban infrastructure are the Internet of Things (IoT), data-mining technologies, and mobile wireless networks such as vehicle-location systems (Liu et al. 2017). Many urban agendas highlight the role of advanced ICT and big data for achieving the goals of sustainable development as well as securing a healthy and livable environment for the city and its citizens (Al Nuaimi et al. 2015; Bibri and Krogstie 2017; Angelidou et al. 2018; Bibri 2018, 2019; Trencher 2019). These long-term transformations in urban planning are also shaping the work of policy makers. New regulatory policies and governance arrangements are needed to spur innovative ideas

and to implement promising solutions efficiently (Martin, Evans, and Karvonen 2018; Bibri 2019; Thornbush and Golubchikov 2019). As pointed out by Bibri (2019, 3), this entails "developing visionary approaches, comprehensive frameworks, and roadmaps for organizing and launching concrete projects, supported by long-term strategic and operational objectives and immediate policy measures for guiding and sustaining the needed transformative processes."

However, the impact of ICT solutions on sustainability issues is extremely complex (Banister and Stead 2004). The most common transitions in the mobility sectors refer to alternative transport vehicles as well as associated technologies, like biofuel or hydrogen-fuel cells (Köhler et al. 2009). To get a clear understanding of how ICT technologies can affect sustainability matters, one needs to distinguish the varying goals that these technologies can help to achieve. As Banister (2008) defined in his much-cited paper on the sustainable mobility paradigm, different aspects need to be considered. Sustainable mobility approaches should therefore reduce the need to travel, encourage a modal shift, reduce trip lengths, and enable greater efficiency in the transport system. As we can see in this case study, ICT technologies differ in their direct results and long-term effects on sustainability issues. For example, certain regulations enforced by digital applications can lead to a direct increase in the efficiency of the transport system. However, the generated data can, in the long-term, also support more flexible traffic planning and therefore reduce trip lengths. This also shows that digital innovations are likely to be accompanied by wide-ranging societal and political restructuring because the existing rules, regulations, and policy instruments must change to match the new digital solutions.

Local policy for organizing modern logistics in urban space

The academic discussion on commercial transport has on two issues: (1) the logistical and infrastructural implementation of the so-called "last mile," for example concerning the costs of transporting goods to their destination (Boyer, Prud'homme, and Chung 2009); and (2) the efficiency improvement and optimization of transport routes, for example concerning traffic congestion or energy consumption (Anand et al. 2012; Rose et al. 2016). Rose et al. (2016) also call for an urban logistics perspective that understands the city as a holistic element with connected subcomponents. Thus, urban logistics also includes social and regulatory aspects between the actors affecting the movement of goods (Ambrosini and Routhier 2004).

According to empirical research findings, the sector of urban logistics is currently characterized by unstable regimes and a multitude of niche developments testing various solutions to different problems (see Table 1). Very few of these concepts have been systematically anchored and translated into long-term and effective use. Pilot projects tend to be rolled out in small areas and end when the sponsoring initiative expires. This observation coincides with Geels' theoretical assumption that unstable regime structures can continue to exist until a convincing socio-technical solution becomes established (see, e.g., Geels and Schot 2007). Different technological solutions are not only competing with the current structures of the regime, but also with other niche developments that are trying to attract the attention of operators and municipal administrators.

Digital innovations are especially interesting because they entail both changes within existing regimes and systematic change for the larger urban environment. For example, the use of an app for parking or loading processes requires systematic changes in the street infrastructure including additional signage, street markings, and tools for the users. These infrastructural initiatives are supplemented by municipally controlled elements like the creation of a large database that can over the long-term result in a holistic and digital image of the city and new regulation mechanisms. This aspect fundamentally changes the functionality of municipal administrations and the efficiency of urban traffic in general.

Smart city development – the case of Barcelona

Barcelona is the second-largest city in Spain and a gateway to the Mediterranean. Both the city and its metropolitan area combine a multitude of logistical activities posing challenges that require in-depth and flexible planning. In addition, Barcelona has a high population density and is the fourth most popular destination in Europe for international overnight visitors, annually hosting 7.6 million

Table 1. Systematics of initiatives and measures of city logistics [based on Erd (2015)].

Initiatives within an existing regime		Initiatives that entail systematic change	
Municipally controlled	Private sector	Infrastructural change	Transport organization
City toll	Bundling	Micro hubs	White-label solutions
Access rules	Management systems	Tunnels	Intermodality
Multi-use lanes	Vehicle innovations	Street infrastructure	
Loading zones	Geographic-information system (GIS), routing	Drones	

people prior to the COVID-19 pandemic (Hedrick-Wong and Choong 2015). Logistics-related space, such as warehouses and hubs, occupies 6.7 million square meters in Catalonia, including 4.9 million in the Barcelona metropolitan area (Barcelona-Catalunya Centre Logistic 2018). These characteristics make it difficult to enforce a sustainable transformation of urban logistics.

The city is also a central location for knowledge exchange and a geographic nexus for disseminating information including the hosting of three expert conferences annually: the "Smart City Expo," the "IoT Solutions World Congress," and the "Mobile World Congress." These major events offer the municipal administration, scientists, established companies, and startups the opportunity to present new ideas to a broad audience. The congresses increase both the local knowledge base and the potential for global networking. At a time when various cities are embracing the discourse on smart cities, Barcelona has managed to position itself as a leading location. However, this status raises the requirements for local developments to realize the claim to leadership in corresponding projects and innovations. Several smart city rankings emphasize that Barcelona is one of the leading cities when it comes to smart sustainable urban agendas. For instance, based on the Smart City Index 2017 by Juniper Research, a market-research firm specializing in digital technology, Barcelona ranks ninth worldwide and third in Europe. In particular, the company highlights the success the city has had deploying IoT-integrated infrastructures. Based on intelligent-traffic systems like smart loading zones, cities can "give back" time to its residents by saving them time through high efficiency in mobility (Juniper Research 2018; Thornbush and Golubchikov 2019).

Local and regional policies aim to master the challenges by implementing new technologies and enforcing urban transition processes. Like in our case study, cities link technology development and urban policy. In Barcelona, the municipal administration's Urban Mobility Plan periodically articulates the goals for the city's future development, always designed for a period of five to six years. The objective is to make delivery processes more socially, ecologically, and economically compatible. This includes efficient distribution of goods, improving the monitoring, control, and availability of information, and incorporating new technologies. For instance, the Urban Mobility Plan 2013–2018 called for implementation of smart loading zones and, thus, the digitization of logistics processes (Ajuntament de Barcelona 2014). Smart loading zones were facilitated in the form of an app-based technology developed by the municipal administration that is now mandatory for all logistics operators in the city. It monitors (un)loading processes in the city and collects a variety of data about the vehicles used. The designated areas for using the app are indicated by new street signs. Before 2015, parking spaces were regulated using the classical method of obligatory cardboard disks, with delivery vehicles permitted to park in signposted zones for a specified amount of time.

The idea of using an app to digitally manage delivery zones was not a direct intention of the policy. Instead, this intervention was devised by a small group within a public company. This development led to the technical foundation of the technology, which was then integrated into the Urban Mobility Plan (Ajuntament de Barcelona 2014). At an early stage of the development of the Urban Mobility Plan, the municipal administration considered other technologies such as occupancy-sensor platforms. However, they were regarded as inefficient and too expensive. In 2017, one of the original developers founded a startup company and received a patent for an upgraded version of the technology, which was afterward integrated in other locations outside of Barcelona, such as pilot projects in the city of Vic north of Barcelona as well as in Dublin (Ireland), Belfast (Northern Ireland), and Stuttgart (Germany).

In this case study, we show how top-down integration caused the development of the second app and how this upgraded version led to geographic diffusion of the innovation beyond Barcelona. To help digital innovations for smart logistics, like smart loading zones, to be successful, it needs new market formations and learning processes that scale-up innovations beyond its niche. The MLP as a theoretical background is a useful analytical framework to further study transitions of digital urban innovations.

Combining insights from transition studies and geography

In the following section, we provide a brief overview of the general assumptions of the MLP and present our conceptual framework for this case study, which enriches the MLP with a geographic perspective to analyze urban transitions.

Recent years have brought a growing focus on the geography of transitions as an emerging research field, yet further case studies and theoretical rethinking are required (Coenen, Benneworth, and Truffer 2012; Truffer and Coenen 2012; Hansen and Coenen 2015; Fastenrath and Braun 2018a). This includes conceptual approaches combining theories from human and economic geography with certain

aspects of transition studies (Boschma et al. 2017). Researchers also highlight the importance of getting a deeper understanding of endogenous characteristics of urban transitions, such as local policies, situated learning processes, and involved actors. This emphasis includes calls for identification of local and trans-local drivers and barriers (Fastenrath and Braun 2018a). Due to their high density, cities can be powerful promoters of sustainable and technological transitions, as they provide crucial resources for successful innovation processes (Truffer and Coenen 2012). Therefore, geographic concepts need a more practice-oriented research focus on the transition-study context (Fastenrath and Braun 2018a).

In this case study, we want to address the rapid urbanization of cities, how digital innovations can contribute to a successful sustainability transition, and how they affect geography and new market formation (Köhler et al. 2019). Municipalities need to pay more attention to the effects of urbanization and the ecological and economic challenges it poses. Research on geographic transitions in urban contexts has tended to focus on various urban experiments such as urban living labs (Broto and Bulkeley 2013; Raven et al. 2017; Marvin et al. 2018). One question that remains open is to what extent such local experiments can scale and transcend their initial geographic context (Turnheim et al. 2018). The issue of digitization primarily manifests in the discourse around "smart cities" (Marvin et al. 2015). Challenges arise concerning the interplay of digitization, automation, and sustainable development, as well as how urban agendas for smart cities and digitization processes can influence the geography of transitions (Coenen, Hansen, and Rekers 2015; Köhler et al. 2019). These transformations are also affecting urban infrastructures and the stability of existing regimes (Köhler et al. 2019).

The MLP on sustainability transitions

The MLP is a conceptual framework for technological developments within a society, based on the work and theoretical basis of evolutionary economics, innovation management, and system innovation (Nelson and Winter 1977, 1982, 2002; Genus and Coles 2008). Recent studies continue to develop the theoretical approach for analyzing current processes in socio-technical regimes, such as innovations and transitions in agriculture and transport (Roberts and Geels 2019), gas and oil (Hansen and Steen 2015), photovoltaics (Yadav, Malakar, and Davies 2019), and low-carbon mobility (Berkeley et al. 2017; Whittle et al. 2019).

Over the past two decades, the MLP has become a well-established theory to analyze socio-technical transitions. It defines three central levels for analyzing transitions (Geels and Schot 2007). First, the niches constitute domains in which a few cooperating actors advance innovation and act as incubators outside the existing regime (Geels and Schot 2007). Within these "protective spaces," technologies can be invented, tested, and made marketable outside of regime-determined selection processes (Kemp, Schot, and Hoogma 1998; Smith, Voß, and Grin 2010).

Second, the regime constitutes a socio-technical fabric of various actors and practices and ensures the status quo of a technological application within society. It represents existing structures that ensure certain connections and modes of action between social space and established technologies. Change within regimes is generally incremental and path-dependent (Smith, Voß, and Grin 2010).

Finally, the socio-technical landscape describes exogenous and superordinate change (outside of niches and regimes) that is usually continuous and slow. Such landscape processes include demographic change, social movements as an expression of social and political demands, changes in the political system, economic development, and scientific or cultural paradigms and attitudes (Geels 2002; Smith, Voß, and Grin 2010).

Transition studies and the MLP focus strongly on sustainable and clean technologies (Binz and Truffer 2017). This bias not only neglects the emergence of other technological innovations but also overlooks how far a technology can contribute to a more sustainable environment. Regarding innovations in the specific area of IoT technologies, it is instructive to consider that this is not a traditional production sector. Digital applications such as apps do not require long value chains which are characteristic of material-intensive and resource-dependent industries. However, digital technologies might require changes in the given physical infrastructure, as well as maintenance and the legitimacy of the software. Recent studies, using the MLP, have started to consider the impact of digitization on transitions, such as the role of so-called e-governance as a socio-technical system (Kompella 2017) or trust transparency and benefit-sharing in smart farming and big data (Jakku et al. 2019). However, there is still a lack of both theoretical and empirical approaches to better understand both the transition of digital innovations and the geography of transitions (Fastenrath and Braun 2018a; Köhler et al. 2019).

Conceptual framework of the geography of transitions

In light of criticisms of the MLP that have been raised over the years, its leading proponents made various adjustments to the framework (Geels 2011, 2014, 2020). In particular, we want to strengthen

the features of the theory that are relevant from the standpoint of the geography of transitions. In its basic conception, the MLP neither references spatial delineation nor differentiates the influence of different spaces. The spatial variation of existing regimes, particularly the (in)stability and change of their structures, has so far been only a marginal consideration (Fuenfschilling and Binz 2018). In particular, new approaches to conceiving of regimes are needed to analytically capture their different forms and geographic complexity (Köhler et al. 2019). A similar charge applies to niches, where it can be assumed that local knowledge networks are important to the initiation and development of an innovation. The elements of the landscape, such as social movements, discourses, values, and norms, are by no means equally influential in any spatial context. On one hand, there is growing acceptance of green politics and environmental awareness in some places. On the other hand, an antagonistic political response to these commitments has been growing. The interplay of these spatial factors could explain the emergence and success of certain innovations since transitions cannot occur anytime and anywhere.

Regarding this spatial focus, urban transitions are highly variable in space and time due to their societal and political embedding. Fastenrath and Braun (2018a) describe sustainability transitions as changed practices in the broader socio-spatial context and highlight the interplay of politico-institutional, socio-cultural, and economic structures (see Figure 1).

In their conceptual framework, Fastenrath and Braun (2018a) highlight three analytical entities and their respective interactions for analyzing urban sustainability transitions:

Pathways: The role of pathways in sustainability transitions has been widely acknowledged in the research community. However, a spatial perspective offers potential new insights on how paths develop across space and time. Generally, socio-technical transition processes unfold over several decades (Geels 2002). This general interpretation makes it even more important to also be attentive to fast-evolving processes within transitions. There has to date been a lack of research on the outcomes of policies in urban transition contexts (Coutard and Rutherford 2010) and Fastenrath and Braun (2018a) indicate that there is a need for a larger emphasis on interactions between technological use and adoption and the outcome of learning processes in a socio-spatial context.

Changed practices: A strong focus also needs to be devoted to how changed practices and learning processes are embedded in city contexts and how they influence transitions (Malmberg and Maskell 2010; Shove and Walker 2010). This includes knowledge generation, spillovers, and specialized skills that can be the result of policy action. These changed practices can be niche-driven and bottom-up processes as well as top-down directed policies (Fastenrath and Braun 2018a).

Figure 2 illustrates the practice change in sustainability transitions. Practice change in this meaning refers to changed policies or innovative practices due to learning processes and knowledge creation. New policies can thus influence innovative practices and vice versa. However, a successful knowledge transfer requires adaptive practices and learning processes during the whole process. Resistance by some involved actors can lead to technological lock-

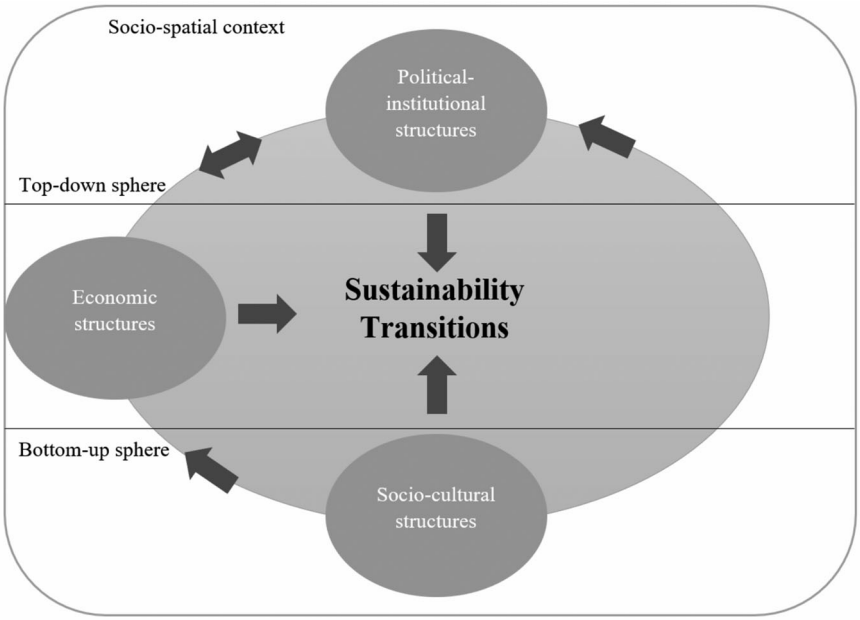

Figure 1. Sustainability Transitions dynamics, Fastenrath and Braun (2018a, 8).

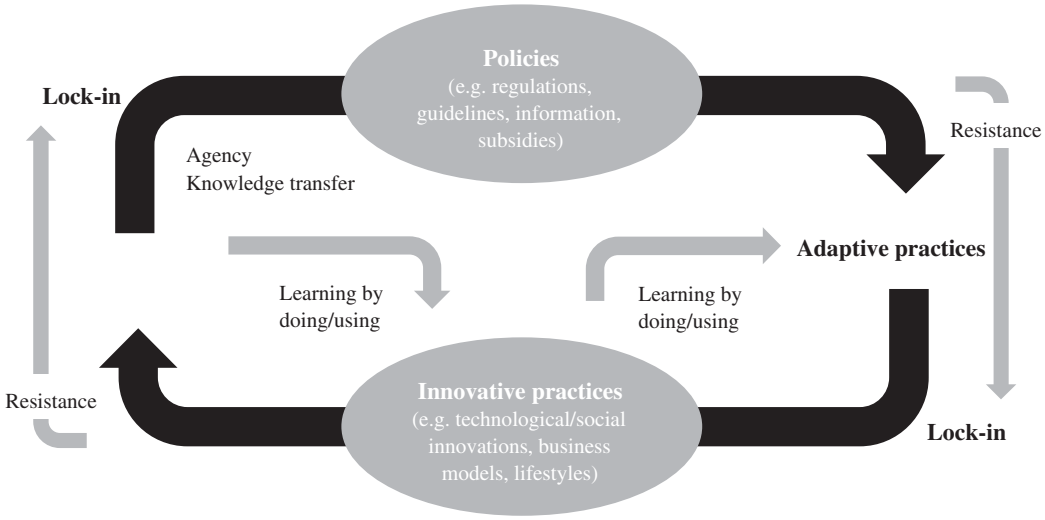

Figure 2. Practice change in sustainability transitions, Fastenrath and Braun (2018a, 9).

in. However, it can be difficult to analyze these complex processes in long-term transition processes across space and time. Therefore, our case study focuses on the development of a single technology, where learning processes and their spatial influence can be more readily examined.

Actors: Actors play a decisive role in several ways when it comes to supporting or hindering transition processes. Urban environments consist of a wide assortment of actors who are essential for a successful transition process. This includes individuals from politics, society, academia, and industry (Fastenrath and Braun 2018a). They can play a key role as catalysts for new practices, technologies, and new narratives in city contexts (Grin et al. 2017). On one hand, local governments can enforce certain technology developments or new practices by top-down decisions or pilot projects within the city. On the other hand, single pioneers can also be crucial as they bring in new ideas and create new niche-driven dynamics in the urban context (Fastenrath and Braun 2018a).

Based on these conceptual precepts, we can begin to deepen understanding of how these categories can be linked in a practice-oriented context. Our case study focuses on this complementary approach and shows how the engagement of transitions agents, changed practices, and learning processes can lead to new pathways in a socio-spatial context.

Digitizing urban logistics in Barcelona

Our research on developments leading to the integration of smart loading zones in Barcelona follows a qualitative approach. This section outlines the study's methodology as well as a comparison of the two apps, especially regarding development, functionality, and sustainability. Furthermore, we analyze the geographic elements of the urban transition in accordance with the categories of the conceptual framework. We focus on the interplay between the relevant actors, changed practices, and pathways of the innovation.

Methodological approach

We conducted several interviews with seven stakeholders in Barcelona who were either part of the innovation process or involved in developing IoT technologies in the logistics sector. These sessions were carried out in Barcelona in November 2018 and transcribed afterward. We followed a guideline containing sixteen questions that focused on personal involvement in the development of the technology, the evaluation of its functionality and modes of engagement with stakeholders, and the social, geographic, and sustainability aspects of the innovation. The main informants were an entrepreneur/app developer and a consultant, both key actors in the platform's development and creation of the business model. The other respondents were part of the municipal administration and scientists from universities and external research institutions. We focus here on a single innovation, namely smart loading zones in the logistics sector. The case study offers a perspective on the relevance of the geography of transitions for a successful and innovative approach with respect to future mobility in cities. Analysis of the regional level role of innovation processes in Barcelona, the structural connection between the IoT and the logistics sector, and multiple regime developments are beyond the scope of this case study but could be explored in future research.

Table 2. Comparison of the relevant features.

	Technology A	Technology B
Operating actor	Municipal administration	Private company
Development path	Policy-driven	Single transition agent
	Top-down	Bottom-up
	Endogenous (single geographic regime)	Exogenous (multiple geographic regimes)
Locations	City of Barcelona	Smaller cities in Spain
		Pilot projects in other European countries
Sustainability impact	Transport efficiency	Transport efficiency
Timeline	2013: Platform development	January 2017: Patenting
	November 2014: Pilot project	June 2017: Platform development
	November 2015: Compulsory use, replacing the cardboard disk	June 2018: Pilot project, export plans
Parking process	Manually by entering a code	Semi-automated via Bluetooth
Parking time	30 minutes	Flexible

Functionality and sustainability aspect of the technology

Table 2 compares the relevant features of the original technology and the upgraded version, though both were typical niche-driven innovations. However, regarding the conceptual framework, the original prototype was a top-down development advanced by the municipal administration. The second iteration proceeded in a bottom-up direction because it occurred outside mainstream politico-institutional structures. Moreover, the technologies differed in terms of their relationship to the regime. While the first app was an endogenous development for urban logistics in Barcelona, the subsequent version was deployed in different geographic regimes. A striking feature of the development of the technology are the short periods between piloting, integration, and mandatory conversion to the system. Consequently, there was a relatively short development period, only a brief reflection of the pilot project, and little adaptation time for users. During this rapid implementation, there was no scope for technical upgrades or improvements for the original app.

The basic functionality of the two apps is similar: logistics drivers use the apps to carry out their activities in designated areas. These areas are subject to certain restrictions regarding vehicle type and parking and access time. When the parking process starts, the duration of the corresponding time specification expires. The limitation of time is intended to increase the fluctuation of logistic traffic. The user must carry out the (un)loading process in the specified time. When leaving the delivery zone, the driver must log out. The transmitted data are managed in a respective back office. The back offices aggregate the data and are responsible for the adjustment and planning of the technologies. The municipal administration handles the management of Technology A while the startup company manages Technology B. Both are located in Barcelona. Furthermore, traffic wardens have a complementary app that enables them to control the (un)loading processes when they are near the smart loading zones. They can fine users who exceed the time limit.

The signage for both apps is very similar at first impression: they identify the zone as a logistics area and display the vehicle type, access time, zone code, QR code, and download link. There are then two main differences between the apps. First, with the original technology, the parking time is printed on the street sign and always limited to thirty minutes, regardless of the location. By contrast, with the upgraded version of the app, the parking time is flexibly determined in the back office, depending on the location. Second, the city's technology requires manual entry of the code indicated on the sign during every registration to start the parking process while the new technology automates this process via a small beacon on the back of the sign. The app recognizes the delivery zone via Bluetooth as soon as the mobile phone is within the area and the parking process is executed via a simple confirmation on the smartphone. These two aspects illustrate the increased degree of automation and the decreased need for direct interaction on the part of the user.

The sustainability impact of both apps is similar as they are designed to monitor environmentally harmful behavior. Every vehicle has an emission label that is recorded when registering in the app. This serves two main purposes: First, it allows access restrictions for certain loading zones according to the label category, thus promoting the use of sustainable vehicles, such as cargo bikes or electric cars. Second, the app can adjust the parking situation based on current environmental data, for instance by blocking certain loading zones when smog levels are high. Based on the definitions of Banister (2008), the technology mainly addresses the sustainability aspect of more efficient transport and more flexible mobility policies.

Additionally, the technology could over time contribute to a modal shift by making it more attractive for companies to use sustainable vehicles. This effect has yet to be demonstrated. Nevertheless, sustainability is only a minor aspect of the innovation. Especially with digital technologies, the added value for the environment must be clearly evident. Establishing whether the technology can support a sustainability transition would require a long-term

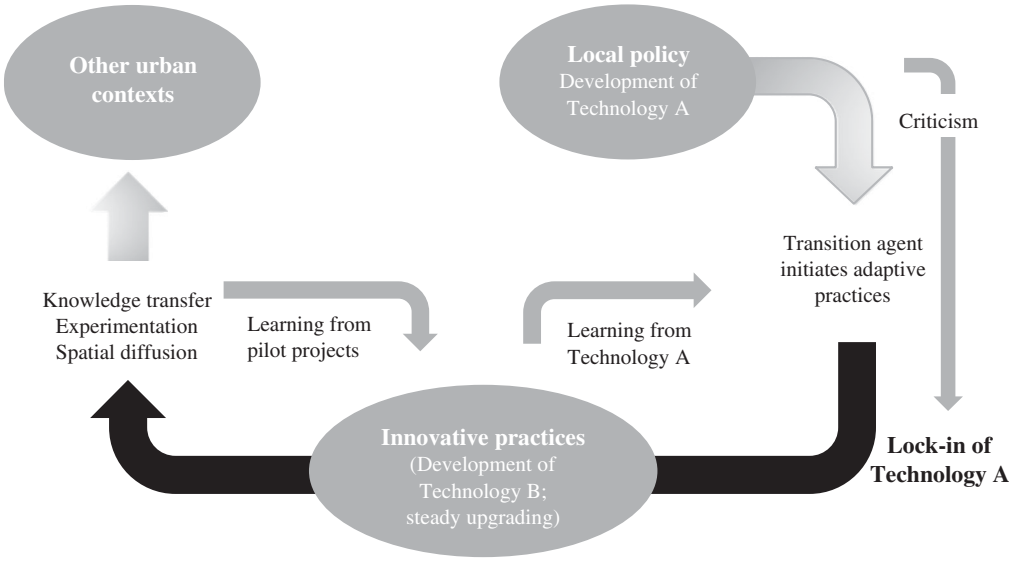

Figure 3. The process of changed practices in the Barcelona case study.

analysis of its actual impact in this category. Since transition studies strongly focus on clean technologies (Binz and Truffer 2017), it is interesting to examine innovations that do not primarily emphasize the environment but have the potential to make a relevant contribution.

The innovative niche development of smart loading zones is a process innovation with both product and structural innovation elements. The app itself, as a new product, is part of a structural embedding, including new space management and signage on the streets. However, the central innovation is the combination of these elements that are thus creating a new workflow process for municipal administrators, logisticians, and drivers.

The interplay of changed practices, actors, and pathways from a spatial perspective

The following section demonstrates how the involved actors changed practices and addressed learning processes in this transition process and therefore influenced the socio-spatial pathways of the innovation.

Changed practices

The most striking issues of the first app were the difficulties directly confronting drivers and users. The app disrupted the routines of drivers by requiring them to enter a code, thereby increasing the time for each (un)loading process. Some drivers were also observed reusing parking spaces, despite the time limit, through repeated registrations in the loading zones. Thus, the digitization process did not lead to effective improvements over the previous situation, but only changed the form of indiscipline. These technical errors and planning mistakes can be particularly problematic in a fast-moving work environment such as logistics where time is the primary resource for satisfactory workflow.

Another point of weakness was the strict time limit of 30 minutes for the loading zones. This restriction addressed the needs and working practices of the courier and express service providers who carry out many deliveries in short time periods. However, they only constitute a relatively small part of urban logistics in the city. The larger proportion of logisticians (such as stores, the craft sector, or construction sites) are limited to individual deliveries that can be very time consuming. Since the app lacked automation, the exceptional cases had to be handled directly by the city officials, causing additional administrative work on both sides. A disagreement between supporters and critics is whether the original technology still has the potential for future adjustments or not. While municipal administrators accepted that there were some flaws in the app, they saw the general potential of adaptation and future improvement of the technology. Moreover, their focus at the time was more on the Urban Mobility Plan and its tendency to emphasize that there are different solutions for different problems and planners should strive to implement adaptive responses. Thus, they successfully created space for experimentation and the piloting of new ideas and technologies. Other respondents outside the municipal administration were less convinced that the innovation in its original form would survive. For instance, an external researcher stated that although the technology provides a nice experience, it will be overhauled sooner or later.

Learning processes and actors

The co-learning process between end-users and developers led to the conclusion that the app needed fundamental improvement to overcome its

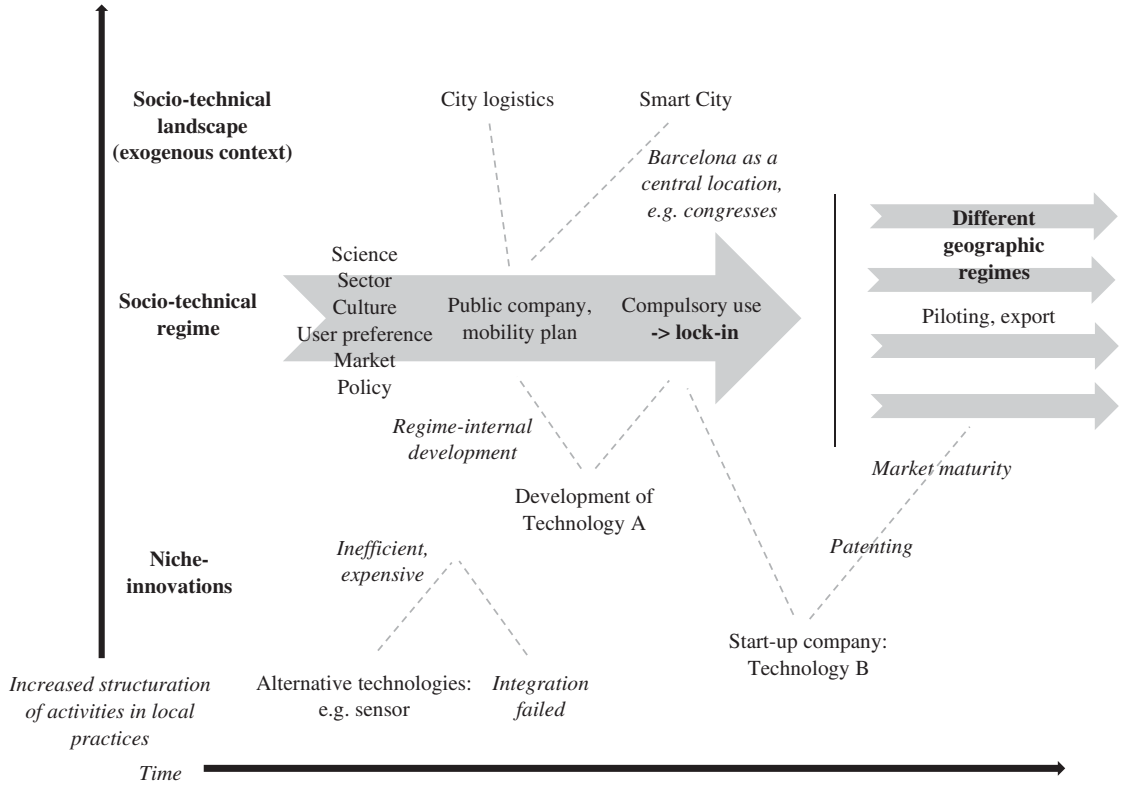

Figure 4. Development of smart loading zones in Barcelona from a multi-level perspective.

technological shortcomings. It was at this point that a developer decided to turn the idea into a startup company because of opportunities to improve the functionality of the app and to commercialize its use to other cities. The flaws in the original version created by municipal administrators reflected the complex actor networks that often exist in urban contexts and demonstrated how effective urban policies have to simultaneously satisfy multiple requirements. As public space is a crucial resource for many residents, unsuccessful technology integration can lead to numerous problems, such as inefficient use of public space or additional effort for the actual users. In the means of the conceptual framework, these issues led to a lock-in (see Figure 3). After the integration of the technology across the city, the municipal administration did not have the resources to overhaul the technology and correct the planning mistakes. Therefore, they were not able to initiate adaptive practices themselves.

The app developer played the role of a transition agent. He was able to realize the adaptive practices that were needed for the upgrading of the innovation. In addition, the more flexible environment of a startup company made it easier to process the feedback of the users and to test the technology in different geographic locales. The upgraded technology is today being tested in different locations outside of Barcelona, including smaller towns proximate to the city as well as metropolitan areas of other European countries. The idea of "local self-government" allows municipal administrations to adopt ideas from other urban contexts and support experimental projects (Fastenrath and Braun 2018a). The transition agent managed to access other geographic regions by networking and initiating pilot projects in other cities and communities. The importance of stable learning processes is essential for the knowledge transfer and the upscaling of the innovation. Moreover, individual pioneers can more easily realize this transferability. The municipal administration also exchanged experiences with other cities, but consequently every location has its own context and it could not adapt the app for other settings. Expressed in other words, the competence of local governments barely exceeds their own borders and it is important for individual actors to bridge the unavoidable differences.

Pathways

The evolutionary path of the integration of smart loading zones in Barcelona can be illustrated schematically using the main features of the MLP. Figure 4 depicts how the local innovation and embedding of the technology led to a lock-in that limited the geographic diffusion of the original idea. The first niche development of Technology A had easy access to the structures of the regime as it was part of the Urban Mobility Plan of the municipal administration. Alternative technologies for monitoring (un)loading processes, such as sensors, were regarded as inefficient or simply too expensive.

However, the hasty integration and compulsory use of Technology A opened the opportunity to make improvements to its current form. The niche development of Technology B successfully added functionalities and got rid of the shortcomings. After the patenting, it reached market maturity and the innovation transferred to different geographic regimes.

Exogenous landscape development played a decisive role in the creation of the Urban Mobility Plan in Barcelona. The municipal administration strongly promoted the city as a pioneer in smart city development. However, there is a paradox in the usefulness of the actual technology: while the idea of a smart loading zone was originally developed in the local context, its improved form appears to be more attractive as an export good. This finding coincides with a key understanding about the socio-technical configuration of world cities: they primarily justify their position by making local innovations exportable and by having intermediary actors who can work both locally and globally (Hodson and Marvin 2010).

The Barcelona case study also clearly shows that it is important to focus on the endogenous context of a specific urban environment (Fastenrath and Braun 2018a). The perspective on a local transition process makes it possible to better understand lock-in processes and adaptive practices, as well as to identify transition agents. A transition process is therefore never a linear or unique phenomenon. The two technologies are now developing independently of each other in different places. This point was reinforced by all of our respondents – although the two apps are evolutionarily related, they are regarded as clearly distinct from each other in their current state and are not competitors.

Regarding our research questions, the case study demonstrates how successful interplay of changed practices, actors, and pathways can transfer innovations across space. We can identify three central characteristics of the geography of the transition. First, socio-technical systems, and especially regimes, are local constructs because geographic proximity and the ability to transition technology to another geographic regime can be crucial for the success of an innovation. Second, a successful transition requires the coordination of all actors anchored in the local regime. Overly hasty integration of technological development runs the risk of failing to meet social and economic needs and not gaining acceptance from certain groups of actors. Furthermore, the financial, structural, and personnel investments that have already been made may prevent corrections to the regime, which could, in the worst case, lead to technological lock-in. Finally, local proximity in urban areas can generate criticism that can lead to new niche developments. Moreover, such experimentation on a local level can also support the diffusion of novel technologies beyond their original borders.

Conclusion

Our case study shows how urban policy can serve as an incubator for innovative developments and thus support transitions through clear structuring, formal anchoring, and creation of space for experimentation. Moreover, localized innovative developments can successfully lead to new socio-spatial pathways if the interplay between changed practices, learning processes, and the involved actors is successful. While the original technology by the public administration set the foundation of the niche-innovation in a local regime, the upgraded version managed to create markets for smart loading zones in other geographic regimes. Regarding the question of how cities shape wider institutional change beyond their initial geography, we observed an unintended upscaling of the actual idea. Although it was not an original intention to market the technology outside the city, this activity was made possible by the ongoing efforts of the transition agent. This highlights the importance of individual actors who are willing to progress an innovation beyond its original geographic context.

The study is limited to the development of a single technology in the context of smart city agendas. Although it provides interesting micro-level insights on urban policy dynamics, we are able to offer only limited conclusions on broader developments. Future research could focus on the regional importance of cities like Barcelona as incubators for smart city technologies. This would allow the theoretical links between evolutionary economic geography and transition studies to be analyzed in more detail. This study also sharpens the necessary focus on transitions in the context of digitization. It shows that the benefits of digitization for sustainable development are often not directly evident but are instead achieved through successful structural change, in this case, by the regulation of traffic during periods of elevated air pollution. There is a strong argument for transition studies to extend their horizons beyond typical sustainable technologies. Future studies might seek to answer the following questions: What structural links exist between the IoT sector and traditional industries using IoT technologies? How can digital technologies break up established regimes and ensure sustainable benefits? And how can urban policy and space as analytical categories be linked on a national or global level?

Evolutionary economics has an essential role to play in enhancing knowledge about regional and urban development in the digital age and in analyzing the potential of a geographic perspective on this matter. The socio-cultural dimensions of mobility transitions are likely to increase in importance as innovations in IoT and other digital technologies emerge while at the same time rely on societal acceptance for their legitimacy. For innovations such as smart loading zones to become sustainable solutions for future mobility within cities, operators and municipal administrators will need to create a consensus and positive environment for these changes.

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Change agency and path creation toward future transport systems: The case of urban air mobility in Germany

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Abstract: The goal of this paper is to gain a deeper understanding of the interplay of change agency and path creation in the emergence of new industries. This study investigates the case of urban air mobility in Germany, including expert interviews with diverse actors. The article highlights the need to consider interdependencies and hierarchies among different types of agency and how these insights are linked to opportunity spaces. The socio-technical integration of air mobility is centered around institutional entrepreneurship and the importance of formal lawmaking. This is exemplified by the dominant role of a few authorities, which have a decisive influence on the path creation, as well as fundamentally different perceptions regarding the technological potential of air mobility among innovative entrepreneurs. Cross-sectoral and institutional dynamics challenge the socio-technical integration of this new mobility form and create an ambivalent environment of insecurity and grand expectations. Technological characteristics of air mobility, as well as regional preconditions and knowledge bases, play a significant role in the formation of the industry. The European Union acts as a catalyst in this development, as proposals guide the making of formal institutions and try to sensitize policy actors and entrepreneurs to engage in experimenting with and further developing this technology.

Keywords: economic geography, Industry 4.0, regional development, opportunity spaces, innovation

1. Introduction

The academic debate about the role of agency for regional development has gained increasing attention in recent years (Boschma, 2017; Grillitsch et al., 2022a; Steen, 2016). While evolutionary economic geography (EEG) assumes that regional capabilities and structural preconditions impact future path development, there is a growing interest in understanding how activities on the micro-scale, such as individual decision-making and practice change, influence the creation of novelty (Boschma and Martin, 2007). Literature on path creation highlights the importance of a relational understanding, where initial conditions and contingencies are the result of human actions, and where actors can use strategic actions to manipulate the mechanism underlying path development (Garud et al., 2010). Grillitsch and Sotarauta (2020) propose the concept of the trinity of change agency, which relies on three distinct theoretical approaches to understanding entrepreneurial activities, namely innovative entrepreneurship, institutional entrepreneurship, and place-based leadership. This paper builds on recent contributions to the topic of emerging industries, institutions, legitimacy, and agency (Gong et al., 2022; Grillitsch et al., 2022b). I examine the case of the evolving urban air mobility (UAM) in Germany, using the proposed trinity of change agency as a conceptual framework for the analysis. The article strengthens the role of actors and agency for path creation in the context of Industry 4.0 innovations that challenge existing socio-technical systems, with an emphasis on the interrelation between diverse types of agency. Regarding novel solutions like artificial intelligence (AI) or the Internet of Things (IoT), it has become a growing challenge for geographers to understand the interconnections between technological characteristics and regional development (Fraske & Bienzeisler, 2020; Gherhes et al., 2022; Njøs et al., 2020). Until now, there have been few empirical studies that provide insights into these developments. Instead of considering the overarching narrative of Industry 4.0 only, geographers need to develop a more differentiated understanding of the specific technologies, their evolutionary background, and their application scenarios (Fraske, 2022). Therefore, this study addresses the following question:

How can the trinity of change agency contribute to the understanding of path creation toward urban air mobility?

To what extent can this case contribute to our conceptualization of change agency?

As evolutionary economics focuses on historical processes (Geels, 2002; Henning, 2019), it is important to not run short of understanding fast-paced innovations, especially considering digitalization. So far, the literature on path creation pays little attention to the question of time-specific dimensions of agency (Grillitsch et al., 2022b; David, 2022). However, this gap offers an important linkage to ongoing debates about windows of opportunity for socio-technical change and their spatial dimension. Moreover, it is crucial to examine multi-scalar and cross-sectoral factors of socio-technical change (Chlebna et al., 2022). Industry 4.0 is often not characterized by single industries but by strong spillover effects. Transport systems have a historical impact on industrial paradigm shifts and vice versa, as they not only

adapt to new innovations but also build the foundation for new value chains, infrastructural upgrading, and social change. The evolution of UAM joins this continuous change in mobility and offers the potential to be one of the central paradigm shifts for transport in the coming decades. As cities seek solutions that relieve ground-based transport and environmental issues, technological developers push the idea of new business cases for both cargo and passenger transport. The development requires system-building activities that address multilevel lobbying and regulatory change (Uyarra and Flanagan, 2022). This article demonstrates that interdependencies and hierarchies among different actors pose a major challenge for an effective change agency. Thus, different types and practices of change agency do not necessarily proceed harmoniously but can counteract the ultimate development goal.

The paper is structured as follows: In the second chapter, I provide an initial overview of the current development and definition of UAM, including use cases and insights from the sector in Germany. In the next chapter, I describe the theoretical framework of this case study, based on the trinity of change agency and path creation. Chapter four gives an overview of the methodological approach. Subsequently, chapter five provides a comprehensive analysis of the case, while chapter six discusses the empirical findings from the perspective of change agency. Finally, I conclude with the findings of this case study.

2. Urban air mobility – toward a new form of transport?

Urbanization and sustainability issues put an increasing strain on existing urban transport systems. Innovations associated with Industry 4.0 foster the creation of new automated forms of mobility, such as UAM. The various application scenarios can be divided into two core aspects: the transport of goods or materials with cargo drones and passenger transport with air taxis.

The academic literature on the topic is primarily techno-centric or business-oriented with several open research agendas (Straubinger et al., 2020; Sun et al., 2021), while only few contributions address urban studies or explicit socio-technical research (Mavraj et al., 2022). Early concepts and imaginations of air taxis or flying cars go a long way back until the early 1910s. However, they never reached commercial viability or sufficient market creation in the last century (Cohen et al., 2021). The topic re-emerged in the last decade, starting with a strong focus on cargo drones and quickly expanding its narrative and experimentation to passenger transport. Regulations, visions, and expectations vary, which makes it important to understand the territory and societal context for tackling the long-term risks (Nneji et al., 2017).

UAM encompasses different concepts, vehicle types, functionalities, and application scenarios. Unmanned aerial vehicle (UAV) refers to the actual vehicles that are developed for operations, such as drones or air taxis, whereas unmanned aircraft system (UAS) refers to the overall systems that enable the operations, such as communication, AI, IoT, or big data applications (Cohen et al., 2021). Drones or air taxis concepts differ in their propulsion, design, technology (e. g. vertical or short-runway takeoff),

capacity, range, autonomy, and compatibility with existing infrastructure and operational systems (Cohen et al., 2021; Thipphavong et al., 2018). The smaller cargo drones primarily address the necessary payload for specific types of logistics, while air taxis aim for an efficient combination of reach, energy management, and passenger seats for commercial viability. Today, over 200 different concepts for passenger drones exist, with twelve prototypes for upcoming certification (VUL, 2021). In Germany, there are three leading air taxi companies: Airbus Urban Mobility, Volocopter, and Lilium. So far, these companies account for the highest media coverage on a national level, e. g. Volocopter is planning the first European air taxi routes for the Olympic Games 2024 in Paris.

Besides, high volumes of venture capital mark the UAM sector, especially in air taxi development. In 2020 and 2021, investors put over 5 billion $ in the nascent sector. Six companies alone account for 4.6 billion $ of the investments including Volocopter and Lilium. This is ten times as much as in the ten years before and stresses the risk that the valuation runs out technological maturity too fast (Shaposhnikov, 2021). Subsequently, air taxis accelerate the discourse and development toward UAM, raising the question of whether this development overwhelms smaller drone developers, or whether they can potentially benefit from it.

Despite the hype that surrounds this new mobility form, the sector is still rather small. Since surveillance, maintenance, or photography have lower entry barriers, most companies address the transport sector only partially or in a specified way. Practical integration is hindered by capacity problems (compared to cargo vans), social acceptance, demand, and primarily the lack of regulations in Germany and Europe. The European Union Aviation Safety Agency (EASA, 2021a) highlights noise, safety, privacy, community or self-benefits, visual annoyance, and environmental impact as the most critical societal acceptance factors. Figure 1 provides an overview of potential transport use cases for UAM, based on own experiences and empirical work.

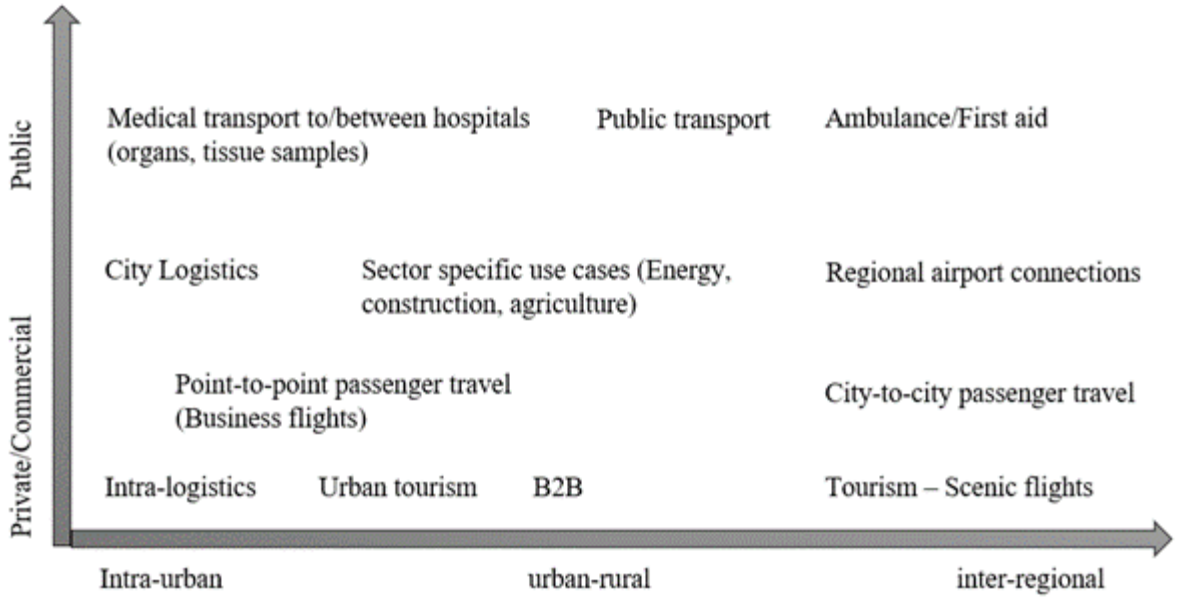

Figure 1: UAM use cases for transportation, own elaboration

The spatial dimension of the specific use cases also defines the competition with other mobility forms. Private intra-urban passenger flights would therefore primarily compete with taxis or the subway, while regional or city-to-city flights would challenge (high-speed) trains or intercity bus services. Moreover, UAM can create fundamentally new business models, like air taxi tourism or sector specific logistics operations. The opportunities for different use cases are also dependent on the societal, political, and topographic conditions of a region. Aside from acceptance and business cases, UAM requires ground-based infrastructures for maintenance, take-off, and landing (so called vertiports or vertihubs), which present urban planners with the challenge of efficiently integrating this new mobility form.

The financial, societal, and environmental risks of this new mobility form underline the necessity of a careful and participative approach by the involved actors. UAM will have to justify its ambiguities and highlight its usefulness to a broad range of different stakeholders and civil society if it aims to contribute to the pluralistic mobility of this century. This unique challenge of forming a new paradigm of transport places enormous pressure on all involved actors, both commercial and societal, in defining a common sense, a sufficient balance between technology and societal needs, and legal frameworks for an efficient operation system.

3. Theoretical background

Gregory et al. (2011) define human agency as “the ability of people to act, usually regarded as emerging from consciously held intentions and resulting in observable effects in the human world.” While reproductive human agency tries to maintain the status-quo, transformative agency tries to break with existing paradigms and establish novelties in existing development paths (Coe and Jordhus-Lier, 2011). Insights from research on ecosystems and agency stress the fact that, besides innovative economic

activities, there needs to be a stronger emphasis on behavioral and cultural dimensions of agency to strengthen entrepreneurship that leads to transformative renewal (Huggins and Thompson, 2019). Therefore, we need to deepen our theoretical understanding of how a more differentiated perspective on entrepreneurship and the initiation of new breakthrough technologies can explain path creation. This encompasses the role of geography and the time-, place-, and scale-specific dimensions. This case study draws from recent conceptual debates in EEG and specifically refers to the trinity of change agency (Grillitsch and Sotarauta, 2020) as a conceptual framework, as it provides a promising conceptualization for the differentiation of agency types and how they can be linked to opportunity spaces and structural conditions.

3.1 The role of agency in evolutionary economic geography

EEG puts a strong emphasis on sectoral relatedness, unrelated variety, and path-dependency in industrial development (Boschma and Frenken, 2006), but it runs short of explaining how innovations emerge and enter existing socio-technical regimes (Njøs et al., 2020). Boschma (2017) points out that EEG often ignores micro-level phenomena regarding path creation and why some regions are more successful than others despite similar preconditions. Moreover, Njøs et al. (2020) criticize EEG for the lack of theoretical and analytical clarity regarding technological characteristics and how they shape new paths for industrial development. Initial conditions are, therefore, not given, but also constructed by the actors involved (Garud et al., 2010). Research on Industry 4.0 reflects this criticism, as there are few forerunners who create novelty, and expectations and narratives surrounding these technologies often exceed the practical state of the art (Fraske, 2022). This highlights the relevance of an evolutionary geographic perspective that does not remain on a superficial level of micro-level analysis but puts a stronger emphasis on purposeful and meaningful decisions by actors that create both intentional and unintentional outcomes (Grillitsch and Sotarauta, 2020). Rather than focusing on a path dependency perspective, this case study emphasizes the understanding of path creation. Thus, the interest here lies in exploring how actors strategically shape socio-technical processes and how serendipity can also be cultivated (Garud et al., 2010).

While some authors criticize EEG for a lack of understanding of green industries and path creation toward sustainability (Grillitsch and Hansen, 2019; Trippl et al., 2020), the same shortcoming emerges for the innovation development toward Industry 4.0. While neighboring disciplines account for most of the empirical research on that topic so far, there is also a strong leaning toward quantitative approaches and a lack of sector-specific research. This perspective falls short of explaining technological differentiation and its impact on regional development (Fraske, 2022). Cities can become powerful promoters of technological transitions, as they provide crucial resources for successful innovation processes (Truffer and Coenen, 2012). Such examples of urban tech or urban living labs cluster primarily in specialized regions that are tied to the innovation capabilities of metropolitan areas (Florida et al., 2017). One question that remains is to what extent such local experiments can scale and leave their

initial geographic context (Turnheim et al., 2018) and how narratives surrounding the "urban" can be translated to spaces beyond urbanized areas. A more precise conceptualization of agency can contribute to our understanding of how innovations in the context of industry 4.0 are socially anchored and why certain cities or regions take a leading role in this process.

3.2 The trinity of change agency for path creation

To bridge the theoretical understanding of regional development and transformative agency, Grillitsch and Sotarauta (2020) propose the trinity of change agency as a holistic approach to study human agency from a geographical perspective. It relies on the understanding of three different approaches to understand entrepreneurship: innovative entrepreneurship, institutional entrepreneurship, and place-based leadership.

The idea of innovative entrepreneurship goes back to the initial works of Schumpeter (1911), who was the first to highlight the role of intentional actions by individual actors for path-breaking economic development and how actors combine knowledge resources in novel ways. This type of entrepreneurship aims toward the discovery and exploitation of opportunities to create value and work toward new industrial specializations, also including unexpected outcomes of actions (Grillitsch and Sotarauta, 2020). Entrepreneurs therefore need to provide the willingness to create something fundamentally new (Schumpeter, 1911). Schumpeter distinguishes between economic actions that, firstly, are based on past experiences and rely on market and technological knowledge and, secondly, those that are driven by a belief in future opportunities (Grillitsch and Sotarauta, 2020). Digital innovations often rely on both incremental and radical types of innovations, as they combine existing structural preconditions with breakthrough approaches that create new business models and technological settings. This is exemplified in the development of autonomous cars by combining existing knowledge from the automotive sector with robotics, AI, and IoT.

However, economic actions are not limited to a purely innovative outcome but contain a mutual connection to institutional change (Granovetter, 1985). Therefore, institutional entrepreneurship defines the second type of agency, referring to actions toward transforming or creating formal and informal institutions that are crucial for regional development (Grillitsch and Sotarauta, 2020). Institutions refer to the question of how social practices shape the entrepreneurial environment. In terms of regional development and economic geography, this addresses rules and regulations as well as economic, political, social, and educational organizations (Grillitsch and Sotarauta, 2020; Storper, 1997). Moreover, institutions can be divided into formal or "written" institutions as well as informal institutions, which can be described as "specific legitimate patterns of interactions displayed at the localized level of agency" (Glückler and Bathelt, 2017). The importance of institutions becomes apparent with a perspective on mobility in general, as technological infrastructures, social practices, and traffic management intertwine in various ways and create a unique but sensitive environment for innovation. New transport systems reflect this institutional change. Firstly, formal institutions like legal

frameworks for system integration need to be adjusted. In terms of UAM, this includes legislative redefinitions of airspace, rules for operation and certification of new vehicle types, as well as rules for integration alongside existing infrastructures. Secondly, new forms of transport enter a sensitive and complex environment where several actors are embedded in the same place and must address new practices that come with the use of a new mobility form. In the initial development, this especially accounts for the legitimacy and how entrepreneurs can enforce an integration that highlights the potential benefits instead of strengthening existing inequalities or pessimistic expectations.

Finally, the role of place-based leadership refers to the role of key actors and how they can benefit from regional preconditions and vice versa. This type of agency aims at efficient networking, bringing competencies, powers, and resources together and therefore strengthening individual and regional objectives (Sotarauta, 2016). Besides regional preconditions, some authors highlight the importance of global linkages to access extra-regional knowledge (Isaksen and Trippl, 2017; Saxenian and Sabel, 2008). Besides accessing collective resources on a regional level, it is crucial for innovative entrepreneurs to address regional disadvantages or build up missing resources (Grillitsch and Sotarauta, 2020). The evolution of new industries is often tied to new policy initiatives, which try to bundle competencies in proactive networks and accelerate the development of industrial clusters, research, and forerunner projects.

The interplay of this trinity of change agency provides a holistic understanding of how path creation can evolve and bridge novelty with existing structural patterns. A common concept is the idea of opportunity spaces, which bridge the socio-technical niches with the regimes and enable novelty to enter new systems (Perez and Soete, 1988; Tyre and Orlikowski, 1994). Grillitsch and Sotarauta (2020) understand opportunity spaces as mediators between the trinity of change agency and structure, as actors are embedded in specific opportunity spaces. They define three different dimensions of opportunity spaces:

(1) Time-specific opportunity spaces are defined by the knowledge, institutions, and resources at a specific moment in time, e.g., funding programs, spaces for experimentation, collaborating networks, forerunner projects.
(2) Region-specific opportunity spaces are determined by the regional preconditions, e.g., existing knowledge bases and clusters, policy support, availability of labor force or spill-over effects.
(3) Agent-specific opportunity spaces are provided by the capabilities of individual agents to make a change, e.g., actors with access to important organizations, the ability to enforce institutional change, groundbreaking inventions, or ideas.

When analyzing agency empirically, researchers must consider some methodological challenges to ensure a clear definition of the aim and scope of the research (Grillitsch et al., 2021). This case study wants to put an emphasis on the emerging UAM sector in Germany. As empirical studies on the micro-level level of human agency focus down to the actual individuals, it is also crucial to acknowledge the importance of organizations, groups, or networks (Grillitsch and Sotarauta, 2020). UAM illustrates this

circumstance, as the embedding of new legal frameworks is tied to the competences of certain authorities in planning and mobility policy. The next chapter will provide an overview of the methodological approach and sources of information for this case study.

4. Methodological approach

This case study follows a qualitative research approach. Table 1 summarizes the sources of this methodology. The primary sources of empirical work have been materialized by conducting semi-structured expert interviews with companies and cluster initiatives that are involved in the development of the UAM sector. The interviews were conducted between March and May 2022. The included companies must fulfill at least one of the following criteria: (1) produce, develop, or operate transport drones or air taxis, (2) create necessary hard- or software platforms or associated technologies for UAM, (3) participate in UAM research projects or living labs. The interview partners were either CEOs or in a leading role within the company, like business managers or strategic developers. Most interviews were held in German and were subsequently translated. The interview guideline was structured in four overlaying topics: (1) The individual role and embedding of the respective interviewee, including his position and responsibilities in the organization as well as intentional short- and long-term development goals. (2) The understanding of technological development, referring to the general functionality of the innovation, connections to the transport sector, unique elements (e.g., patents), as well as competition in the market. (3) The specific elements of entrepreneurship in UAM development, discussing skills, capabilities, risks, and the importance of rules, norms, and routines. (4) The spatial embeddedness, including local and global dynamics, collaborations, funding programs, export ambitions, and regional differences. Due to the early development of the sector, it is crucial to gain insights from different perspectives of the emerging value chain, the respective actors, and their knowledge backgrounds. I identified potential interviewees through existing networks, public documents, search engines, and snowball sampling during the interviews. The interviews were subsequently coded and analyzed with MaxQDA.

Source	Scope
Expert interviews	22 interviewees from 19 organizations - 14 companies: five UAV/UAS developers, seven system- and service- providers, two consulting companies - Five cluster initiatives from different regions
Project involvement	Insights from a project dealing with scenario development for UAM. Insights include primarily: - Exchange with various actors, e. g. municipality, local networks, and research and development (local universities and research facilities) - Review of existing literature and own previous work on the topic
Public documents	Policy agendas and legal frameworks from European, national, and municipal authorities and industrial market research
Media coverage	Articles on current developments, emerging use cases, and press interviews

Table 1: Sources of the case study

Moreover, I am part of a project that deals with scenario development for UAM and have conducted previous academic work on the topic, including but not limited to two systematic literature reviews. In the applied research of the project, I primarily deal with questions surrounding the ground-based infrastructure of UAM from an urban planning perspective. Secondary sources are accessible public documents and press releases that provide insights on policy agendas, legal frameworks, and current developments in the evolving sector. Publications that deserve special mention are the latest agendas provided by the EASA, especially the proposal for the implementation of U-spaces in Europe (EASA, 2021b), social acceptance studies (EASA, 2021a), policy guidelines (UIC2, 2021), as well as industrial market research (Reiche et al., 2018; VUL, 2021).

5. UAM path creation - The case of Germany

In the following, I analyze the current development of UAM in Germany based on the theoretical framework of change agency. Firstly, I provide insights on the market creation process from an innovative entrepreneurship perspective. Secondly, I discuss the institutional dimension with an emphasis on multi-scalar dynamics for framing rules and legitimacy toward this new mobility form. Thirdly, I identify place-based leaders for path creation with a focus on five regional cluster initiatives.

5.1 Innovative entrepreneurship – Emerging markets and discourses

The nascent topic of UAM forces companies to fulfill several requirements across the value chain. Most companies have a clear understanding of their primary goal or sectoral identification, but they must provide additional services or operational tasks since there are no established external partners available yet. The qualification of the entrepreneurs often defines the self-image of the company. In general, most interviewees describe the market as very untransparent yet, both referring to competitors as well as potential partners. Many firms conduct their own initial market research to sharpen their focus and understanding of the solutions. However, there is a fundamental distinction in the background of the companies involved in the development of UAM. While one group of actors has their background in the traditional aviation sector, the other addresses the topic from a mechanical engineering perspective, primarily from the automotive sector but also Industry 4.0 robotics like AI and IoT. This difference becomes apparent in the pure definition of what UAVs are. While actors with an aviation background understand them as another form of aircraft, entrepreneurs from robotics highlight significant differences in these understandings:

"Basically, we consider drones as one more sensor in the industry that is not wired. […] How do we break the existing "encrusted" structures of manned aviation that they can arrange with these new IoT devices as well? […] Our aim is to make flying itself a minor thing. Many people from aviation have so much fun flying that they sometimes forget that it is only a means to an end."

(Business developer, Interview 6, 2022)

This statement also reflects a common criticism that companies without linkages to aviation highlight, as the sector is regarded as locked in conservative approaches and a lack of innovative creativity. Actors with a background in automotive strongly refer to the "flying car" narrative and share grand expectations for UAM in the context of individual transportation:

"In the modal split of the future, UAM will play a similar role like the automotive industry did in the 20th century - if it is done right. The big mistake is that many focus on a premium market. This will not be socially accepted. The image of flying has also greatly improved with cheap flights. […] In the aviation industry, they are used to subsidies, but there will be none for UAM. […] As for economies of scale, only automotives are self-sustaining today, aviation has never accomplished that."
(CEO, Interview 10, 2022)

In contrast, actors from the aviation industry highlight several critical issues regarding the development of UAM outside of the traditional boundaries of the sector. Aviation engineers point out the lack of technical detailing, consideration of certification, and understanding of the aerospace context. They criticize concepts by new UAM developers as generic and emphasize the general criticism that the hype outruns the practical advancements:

"The challenge I see here, is that a lot of market players are not from aviation. That is good in one way, but they do not have the sensitivity to the probability of failure. Everyone wants to make a car fly. […] The most critical inexperience in this market comes from the huge hype of advanced UAM. […] Promise the impossible and take the money for it." (CEO, Interview 11, 2022)

This highlights the second apparent distinction between the expectations and advancements of the sector, namely between cargo drone companies and air taxi developers. Since logistics has a lower entry barrier, most air taxi developers also address cargo use cases. The interviewees have differing opinions on how cargo and passenger transport developments are related in terms of actors and innovation. At the interface of the aviation and robotics background, they share the same operational constraints, legal frameworks, and service providers. On the contrary, they differ in the actual markets, the initiating actors, and the socio-technical environment, which is described as fundamentally different:

"Air taxis and transport drones are two different planets, with completely different players and customers. […] As a car manufacturer, it is en vogue to deal with air taxis. […] I see this topic very critically: Let´s assume they can´t keep their promises in ten years. Then we have a Wirecard case. […] I see the danger of a bubble bursting […] when Silicon Valley and venture capitalists withdraw because they lost a lot of money. Then the whole industry, including our sweet small drone industry, will have a problem." (CEO, Interview 1, 2022)

Despite their technological specifications and own network environment, both use cases share the same narrative and, therefore, are also dependent on the perception of each other. The most crucial questions for scenario building for most companies are, therefore: What can we accomplish? What are we allowed

to do and where? And what are the viable solutions? As the entry barriers differ, innovative entrepreneurs need to constantly review current market developments and new emerging application fields. Their economic activities need to be aware of public perception and fast-paced market dynamics to successfully create or enter windows of opportunity and accelerate commercial adaptation. Most applied projects are "*driven by the opportunity itself*" (CEO, Interview 8, 2022) rather than by strategic planning or clear intentions, which highlight the importance of networking and force encounters to uncover unknown capabilities.

In the current socio-technical development, the availability of venture capitalists and cooperations to initiate pilot projects define agent-specific opportunity spaces. Forerunners on a micro-level as well as big players are crucial to bringing the topic forward. Opportunities spaces are also highly place-specific, depending on the different legal frameworks and corporate cultures on a national level. Different preconditions impact the way entrepreneurs approach their innovation. While the US is heavily tech-driven by private companies, the development in the EU primarily draws from inputs of the EASA. While all actors are in favor of the growing engagement by EASA, there is also an awareness of the slower technological development and socio-technical integration in Europe. As market creation is much more regulated than in other spatial contexts, there is a concern that the next digitalization step cannot grow to its full potential in Germany:

> *"First there was e-commerce, then cloud technology that we have "overslept," and now comes the third thing. […] With our laws and regulations, it is not that easy to get something going. […] For testing and experimenting, we switch to other countries."*
>
> (Business developer, Interview 6, 2022)

5.2 Institutional entrepreneurship and system agency

The institutional dimension of the current UAM development can be divided into two core aspects: The evolution of formal rulemaking and legitimacy. All actors involved share the same insecurity when it comes to changed practices due to new policy guidelines. The most important aspects that need to be standardized in this regard are "*the technical networking, operational procedures, and security*" (Business developer, Interview 13, 2022). So far, the most important legal framework for UAM operations is the U-Space proposal by the EASA (EASA 2021b). U-Spaces are geographically defined areas that should work as a guideline for UAS operators to manage drones in an airspace. They should work as a complementary element to existing aviation guidelines and provide a first step to the combined integration of manned and unmanned transport. These frameworks must ensure one balancing act: On the one hand, they need to provide sufficient information for certification and rules for practical operations, on the other hand, they need to be flexible enough to not interfere too much with innovative development or hinder the evolution of scenarios.

Most interviewed companies started their UAM development between 2015 and 2017. The time windows of the opportunity spaces are strongly reliant on EU guidelines and funding programs. They define the temporary dimensions of the development and when to expect viable use case scenarios. System-providers take this into account when developing operational systems for traffic management:

> *"There is the milestone 2023 when it comes to the first U-Space integration. Then we must be ready with certification and everything that goes along with it. […] The objectives move with the political side."* (Product manager, Interview 2, 2022)

While the interviewees saw no necessity for standardization in terms of the vehicles, the major concern is with the surrounding associated system environment for operation and management. One criticism highlighted in this regard is the strong federal bureaucracy in Germany, as responsibilities are often not clear, especially for new market players. The primary challenge for legal rulemaking is to bundle interests and bring together different stakeholders to create a common basis for the establishment of a clear distribution of competencies. Table 2 summarizes the key system agencies that institutional entrepreneurs need to address to developing UAM.

Policy Scale	System agencies	Primary objectives for formal institutions
European	European Union Aviation Safety Agency and Eurocontrol	Providing legal frameworks and guidelines for initiating national policymaking. Forerunner and most important agency for standardization and certification.
National	Federal Ministry for Digital and Transport Deutsche Flugsicherung (DFS)	Primary national agency for promotion, rulemaking, and management of UAM. Air traffic control: Reorganize airspace for autonomous operations and define safety standards.
Regional	State aviation agencies Cluster initiatives	Aviation and airport administration. Project initiation, industrial networking, represent regional interests to the national agencies.
Local	Municipality	Decision-makers for local embedding and use cases; Integration of ground-based infrastructure.

Table 2: Key system agencies, own elaboration

Legitimacy for UAM evolves in two dimensions: Firstly, within the sector itself; and secondly, toward society. Within the emerging sector, the debate about legitimacy refers primarily to the aspects of the distribution of venture capital and the definition of use cases. While some actors highlight the lack of honesty by air taxi developers, others emphasize the need for positive synergies or the early development state of the value chain that is dependent on an open-minded innovative approach. Social acceptance is the most frequently discussed topic of UAM, both in social science literature and policy. There exist some preliminary case studies and surveys that attempt to provide insights on the public perception, however most of them only cover a small scale or are limited to a specific well-perceived context like healthcare. The most striking problem, however, is that many approaches remain on an abstract level

because there are simply no UAVs to observe. The evaluation of the social acceptance often relies on pure imagination:

"To provide added value for society is probably the most important and difficult topic for local authorities. Address all relevant stakeholders, taking the existing infrastructure into account. Listen to all the concerns, build up communication channels. There are so many emotions involved in these projects, you must give them some space." (Business developer, Interview 2, 2022)

Besides projects that aim to reflect the potential acceptance level of UAM, unexpected feedback can also impact the perception. This is especially interesting because the developers have less influence on the discourse, and potential benefits can get lost in social media or media coverage of a project. One entrepreneur reflects on his experience from a project that tried to conduct cargo transport for tools and spare parts:

"Maybe you cannot necessarily take social media as a reference; comments are always devastating there anyway, but we got feedback like: "Someone is saving money or time, but it's neither my money nor my time and I'm bothered by the noise." Even if the cargo van that passes by today is much louder. But people are already used to that one." (CEO, Interview 8, 2022)

5.3 Place-based leadership and emerging clusters

To date, five cluster initiatives exist that are dedicated to UAM integration in a particular region. These clusters have formed in the context of "The Urban-Air-Mobility Initiative Cities Community of the EU´s Smart Cities Marketplace" (UIC2) and issued themselves in a memorandum as representatives of the local level to act jointly toward the national authorities. The core aspect of this project is to formally define the importance of the municipalities in the development of this new form of mobility and to position the cities in the process from the beginning. This should prevent local authorities from being insufficiently involved in decision-making and counteract possible top-down mechanisms:

"We, as a municipality, want to be regarded as a competent partner. This shouldn´t be an E-Scooter-like scenario: they were suddenly there, and the city had to deal with them. […] We want to be integrated into the process continuously, and then we can still decide whether we feel capable enough or if we want to outsource something." (Cluster Manager, Interview 15, 2022)

Table 3 provides an overview of the existing UAM clusters in Germany. *Hamburg* formed the first UAM-related cluster in Germany and the other initiatives see the city as a pioneer in industrial development as well as U-Space integration. Industrially, the existing aviation sector has a substantial influence on the cluster. As a federal German state, Hamburg also combines municipal and state authorities, which stands out as a salient feature and benefit for the institutional change. The *Aachen* Cluster is part of a five-city cooperation and the only one that operates on an international level. Key actors are a heterogeneous composition of local research facilities. The objective is less geared to broad

network management and regular working groups, but to selective calls for funding, which then leads to added value for the research institutions. The cross-border aspect plays a greater role in the applied projects, although partner cities in Belgium and the Netherlands have dealt with the subject more reserved. In contrast, *Ingolstadt* forms a less spatial focus. The cluster has a much stronger emphasis on the development of individual transport with air taxis and a higher presence of robotics and AI. Although local projects exist, the members compose of diverse companies from across Germany. The focus here lies more on technology development along the entire value chain and less on a specific regional application. *North Hesse* is the only cluster that does not define itself as a central urban location. The cluster related to the logistics industry is the only one not clearly anchored in aviation or robotics. Rather, the aim is to sensitize the logistics sector itself to UAM and to promote potential fields of application. In addition, as a rural region, the cluster emphasizes the importance of considering advantages for UAM outside of urban and economic centers. *Berlin/Brandenburg* is the youngest of the clusters initiated to date. While initial thoughts on the topic were formulated in 2019, they began to come more into focus by the end of 2021. Existing projects tend to focus on rural areas, such as fighting forest fires in Brandenburg. Ideas about the integration of air taxis in Berlin itself are still in an early conceptual phase.

Region	Embedding/Initiation	Scope and Scale	Primary objectives
Hamburg	Part of aviation cluster (one of six specialized sub-clusters) 2017	Linked to existing aviation industry 50+ members, > 90% from Hamburg Metropolitan/urban focus Combines municipality and state authorities as federal German state	Industrial development Use the existing knowledge base of the aviation industry for development of UAM
Aachen	Part of the municipality Economic development office (Promotion of science) 2018	Primarily research facilities 40+ members Cross-border/EU focus Cooperation with four cities: Liège, Hasselt (Belgium), Maastricht, Heerlen (Netherlands)	Research and Development Unique international network environment; Current focus on passenger transport and healthcare logistics
Ingolstadt	Part of the municipality Economic development office (Promotion of science) 2018	Broad sectoral and spatial network 60+ members Trans-local evolution Local key actors, but no spatial focus in terms of membership and development	Technology development Stronger focus on passenger UAM due to southern air taxi developers, also strong presence of robotics/AI
North Hesse (Kassel)	Part of logistics cluster 2018	Primarily logisticians 120+ members (whole cluster) Regional and rural focus Regional big players, but mostly not directly linked to UAM development	Sector-specific integration Integration of UAM in structurally weaker regions; Focus on cargo transport and intra-logistics
Berlin/ Brandenburg	Part of transport, mobility, and logistics cluster (Sub-Sector Aerospace) 2019	No direct membership Urban-rural perspective Few big players, primarily strong start-up culture	Project initiation Early adaptation; Focus so far on rural projects, concepts, and individual service for companies

Table 3: Preconditions and capabilities of regional UAM clusters, own elaboration

The diversity of the regions, which all focus on specific applications, underlines the intention that UAM should be viewed as holistically as possible for future scenarios. All clusters clearly prioritize cooperation for addressing formal institutions, use cases, and exchange with national and European levels. So far, there has been no opposition outside of the competition for funding of project acquisition. A central challenge for the initiatives is the next step towards application scenario building, in particular the creation of a common basis for a commercial application. While the focus so far lies strongly on civilian applications such as in the medical sector, they see the necessity for more business-oriented approaches in the next steps and to think outside the social comfort zone:

> *"At a panel discussion, someone used the fitting term of "baby bunny" projects. […] They are, of course, socially accepted, like medical transportation. […] But in the end, these are innovation projects, and from an economic promotion and regulatory perspective, you must start thinking further."* (Cluster Manager, Interview 16, 2022)

The cross-sectoral conflict lines for innovative entrepreneurship also mirror in the everyday activities of the clusters. In their role as an intermediary actor, they act as the organizational bridge between different knowledge bases and provide a platform for the critical discussion of different approaches:

> *"Sometimes you sit in project meetings and realize that people talk past each other, or they realize that they meant something completely different in a proposal. This is a process of convergence. […] The automotive manufacturers want to do something, and then the aviation engineers say, "Well, if you do it like this, the thing is going to fall from the sky"."* (Cluster Manager, Interview 18, 2022)

6. Discussion

The presented case provides insights on how agency is linked to structural change and fulfills different purposes in creating opportunity spaces for UAM. Moreover, it becomes apparent that some types of agency play a crucial role in the development of innovation and create interdependencies for others.

6.1 Reflecting on the trinity of change agency

UAM combines both ideas of Schumpeterian innovative entrepreneurship. It relies on existing knowledge about the aviation sector while bringing fundamentally new technological concepts and use cases to the evolving market. This duality is not without conflict, since expectations, business models, and technological approaches differ between the two sides. Therefore, UAM provides a good example of how past experiences and beliefs in future scenarios mutually co-evolve (Grillitsch and Sotarauta, 2020). Besides the novelty created in this ongoing process, it also shows how the alignment challenges economic activities and innovative entrepreneurs – not only in a technological but also in an institutional and spatial context. While innovative entrepreneurs address regional preconditions, they are strongly dependent on time-specific opportunity spaces for the integration of their innovation to create spaces for experimentation.

Institutional entrepreneurship evolves alongside national and local policy scales, driven strongly by EU proposals. The formal institutions for the socio-technical integration of UAM are in the making, but at a different pace. Therefore, many German companies experiment in international markets, primarily the US or Asia, to pilot their ideas. So far, they don´t see the business cases on a national level, especially regarding passenger transport. However, many entrepreneurs value the engagement of the EASA as a forerunner and provide positive feedback regarding the existing guidelines and proposals for UAM in the EU. Due to the early development phase, there are no legitimate action patterns that could support UAM or provide clearer insights on how to address society. The creation of this rulemaking remains the most important aspect to be addressed by institutional entrepreneurs.

Considering place-based leadership, all model regions use their previous strengths to exploit opportunity spaces. The leadership role is closely tied to the local authorities or existing cluster organizations. While some follow a more local-industrial or research-oriented approach, others emphasize the importance of sectoral transfer. Small and medium-sized companies constitute the largest group for cargo drone development. In contrast, a few big players, primarily Airbus, Lilium, and Volocopter, as well as companies from the automotive industry, accelerate the air taxi development. Cargo drones offer fields of application with lower entry barriers, whereas the transport of larger goods tends to occupy a secondary market so far. Companies focus on global development and diverse application areas. This makes it difficult to identify any local entrepreneurial leaders, and entrepreneurial ecosystems either do not exist or are only present in a small community.

6.2 Interrelation between change agency and opportunity spaces

A dominant role for the overall progress can be identified in the role of institutional entrepreneurship regarding legislative issues and the agent-specific opportunity spaces tied to this. This accounts for the EU as the main forerunner that sets a narrative and legal guideline, as well as the national authorities and aviation agencies that transfer these proposals to national legislation. The goal of creating a socio-technical system for operation is centered around this legal development. Thus, a few actors strongly determine the scope of this new mobility form. Innovative entrepreneurship must constantly engage with these ongoing debates to keep track of necessary technical adaptations or emerging business opportunities. This creates great uncertainty regarding future development, including fears of insufficient market creation or negative perception by civil society. Moreover, there is a risk of being influenced by the structural power of venture capitalists (Cooiman, 2022). To work toward the long-term outcome of value realization, innovative entrepreneurs focus on providing a flexible solution that is applicable to different scenarios. However, these interdependencies have already led to developers applying their technology in other geographic contexts outside of Europe, including spillovers or even the relocation of their main activities.

Besides, the creation of opportunity spaces is challenged by the place-based engagement of local authorities. While countries like China or the USA have lower entry barriers in terms of legislative

matters, the local authorities strongly engage in framing the topic so that national policymakers do not surpass the practical feasibility. This applies especially to the air taxi development, where municipalities remain hesitant and only see limited potential. The place-based leaders aim primarily for short-term outcomes like building up networks, initiating co-learning, and providing space for experimentation. For this purpose, the existing model regions provide a promising approach by specializing and sharing insights from different practical experiences. Moreover, entrepreneurs desperately try to enforce the exploration of potential funding sources and application scenarios. This aligns with the observation that many projects so far were initiated by perceived coincidence rather than strategic planning, which can be linked to the importance of cultivating serendipity (Garud et al., 2010). This apparent coincidence is part of a process in which the involved actors strive for embeddedness and enforce cooperations through informal exchange. They do so by intentionally screening their environment for opportunities, such as joining networks, attending project meetings or events, and using existing experiences and connections for further development. The challenge here is to identify promising collaborations early on and not invest too much time and capabilities in less productive efforts. Entrepreneurs highlight this obstacle primarily regarding applied research projects, in which the ambitions and outcomes diverge greatly.

The time- and space specific opportunity spaces are strongly dependent on the discourses that surround the development of UAM. Striking here is the unification of air taxis and drones in the narrative, which creates wrong expectations and understandings of the different technological avenues. So far, change agency is concerned with bridging these noticeable gaps and moving toward applicable technical solutions, legislation, and societal acceptance. These common goals are counteracted by spatial disparities and misunderstandings, as well as hierarchies among the different participants. Hence, the case not only illustrates how change agency must be regarded as a space- and time specific phenomenon (Grillitsch et al., 2022b), but also as a research field that considers internal conflict and interdependencies that can potentially hinder the actual process of change.

7. Conclusion

The main objective of this case study is to analyze the interplay of the trinity of change agency to offer a better understanding of an emerging path toward future transport systems, namely urban air mobility in Germany. Based on a qualitative research method, I identified central actors that try to combine innovative, institutional, and place-based activities and use regional preconditions to position their solutions in a broader context. Besides the temporality of agency and opportunity spaces, this case study explores how hierarchies within change agency play a crucial role in the analysis. The case illustrates how different types of agency not only contribute to path creation, but also create interdependencies that can potentially hinder the development goals of UAM. Thus, roles and self-interests of the involved actors can determine both short- and long-term outcomes and significantly influence other participants, discourses, and the socio-technical development itself.

The article provides a comprehensive perspective on current developments, which are taking place in a very fast-paced and dynamic environment. Nonetheless, it emphasizes the importance of a more elaborated evolutionary economics perspective on early developments toward Industry 4.0 and digital innovations to better understand how entrepreneurial activities are linked to structural change. Future research should put a stronger emphasis on the interconnection of different knowledge bases in the context of Industry 4.0, local ecosystems for promoting innovative ideas, and how to address the legitimacy of advanced solutions toward society and local actors. Moreover, the debate on change agency needs to develop a more differentiated view on potential internal conflicts, and how these (hierarchical) processes of disagreement can shape the direction of development paths.

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Legitimation strategies for digital transformation: Insights from the advanced air mobility ecosystem in Hamburg

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Abstract

Purpose: This study inquires into the collective strategies through which organizations engaging in digital transformation legitimize their new value propositions. In doing so, this article aims to corroborate existing theoretical conceptualizations on networked legitimation strategies in emerging entrepreneurial ecosystems by empirically inquiring into the case of a novel value proposition facing particularly high legitimation challenges, the case of advanced air mobility (AAM).

Design/methodology/approach: The study draws on a single qualitative case study of the emerging AAM ecosystem in Hamburg, Germany. The main qualitative study rests on semi-structured interviews with 22 representatives of AAM tech and policy development as well as on a contextualizing document-based social network analysis and insights from applied research projects.

Findings: The findings show that external actors provide significant orchestrating activities in the development of a legal framework and strongly affect the discourses for legitimizing AAM. State-owned companies from the aviation sector have a decisive influence on the emergence of the ecosystem. Local actors and entrepreneurs primarily strive to collaborate, exchange and overcome existing knowledge gaps.

Originality/value: The main value of this study lies in its empirically-grounded refinement of state-of-the-art conceptual frameworks regarding the networked legitimation strategies employed by organizations involved in emerging ecosystems of digital transformation.

Practical implications: This study covers insights for practitioners, entrepreneurs, and urban planners on providing strategic actions and fulfilling legal requirements associated with the socio-technical change during digital transformation.

1. Introduction

Digital transformation is plunging numerous entrepreneurial and governance practices into turmoil. Newcomers disrupt and create markets by creating new platforms (Frenken and Fuenfschilling, 2021) or proposing new ways of managing the flows of people, energy, or goods (e.g., Bulkeley et al., 2016; Coletta and Kitchin, 2017; Cugurullo et al., 2021; McLean et al., 2016). Essentially, digital transformation refers to the process of "socioeconomic change […] that is shaped by the adoption and utilization of digital technologies" (Dąbrowska et al., 2022: 932). Hinings et al. (2018: 53) define digital transformations as innovations that "bring about novel actors (and actor constellations), structures, practices, values, and beliefs that change, threaten, replace or complement existing rules of the game within organizations, ecosystems, industries or fields." Digital transformation, therefore, has two major implications.

First, due to the disruption they cause, emerging technologies in the context of digital transformation face a broad variety of organizational, legal, and social barriers which we refer to as *liability of newness.* In its origin, the term refers to the greater risks that young organizations face in comparison to established organizations and why they are more likely to fail due to their lack of stability, legitimacy, and access to crucial resources (Freeman et al., 1983; Singh et al., 1986; Stinchcombe, 1965). Key aspects for the liability of newness can be disbelief and a lack of evidence regarding the viability of the innovation and its value proposition (Aldrich and Fiol, 1994; Dattée et al., 2018) or doubts in the long-term sustainability (Ansari et al., 2016). To overcome the liability of newness, organizations seek to obtain legitimacy by adhering to social values and norms implied linked to their activities as well as to the larger social system that they are part of (Dowling and Pfeffer, 1975). From a regulatory standpoint, an organization is legitimized when it follows regulatory processes, rules, standards, and expectations set by regulatory authorities (Ladisma et al., 2017). For this, organizations work individually to meet standards and satisfy routine monitoring (Deephouse et al., 2017). New ventures in digital transformation processes need to obtain legitimacy to establish the adequate governance structures needed to operate successfully in the business models (Hinings et al., 2018).

Second, digital transformation is necessarily a *collective endeavor* as it is "enabling, constraining, but also interwoven with, human action" (Hinings et al., 2018: 52). Digital transformation notably entails greater inter-organizational collaboration and interdependence among organizations (e.g. Autio et al., 2018; Nambisan et al., 2019). These new collaboration patterns mean that organizations become structured in entrepreneurial ecosystems. Entrepreneurial ecosystems are "communities of interdependent yet hierarchically independent heterogeneous participants who collectively generate an ecosystem value proposition" (Autio and Thomas, 2020; Gulati et al., 2012). The digital transformation thus not merely requires deliberate processes of legitimacy-making to overcome the liability of newness (Stinchcombe,

1965; Hinings et al. 2018; Töytäri et al., 2017), but these processes rest on *collective* actions between heterogeneous participants of an ecosystem (Thomas and Ritala, 2022). The heterogeneous participants fulfill different roles within an ecosystem as orchestrators, complementors, users, or external actors, which increases the complexity of legitimacy-making. However, while we understand the processes to overcome the liability of newness at the organizational level (Biloslavo et al., 2020), processes of *collective* legitimacy-making for digital transformations are understudied (Hinings et al., 2018). Only recently the questions regarding collective legitimacy-making for digital transformations have gained increased attention (Thomas and Ritala, 2022), and to our best knowledge that calls for empirical testing.

Recent research has put great attention on the legitimizing efforts of orchestrators, and the legitimizing activities of complementors, users, and external actors deserve more attention as well (Thomas and Ritala, 2022). The emergence of ecosystems is tied to the development of regulatory frameworks which can either create positive or negative dynamics for the overall process (Autio, 2022; Alaassar et al., 2022). Existing or emerging hierarchies, for instance, can block access to external resources and delay a development process (Ojasalo, 2008). As new socio-technical systems and technological arrangements require a fundamental change of formal institutions like rules and laws, all ecosystem participants must generate knowledge flows that aim at legitimizing these innovative solutions. This raises questions regarding the knowledge exchange, the redesign of business models, and the change of power relations between the ecosystem participants (Suominen et al., 2018). The lack of institutional support for young organizations is a crucial factor regarding the liability of newness (Singh et al., 1986) that also reflects in the context of digital transformation (Hinings et al., 2018). Institutions evolve not only at a different pace but are also dependent on the spatial preconditions of a given area, such as different aviation safety standards in different countries. Moreover, it is unclear under which conditions actors' effort in the form of regulatory dynamics leads to positive legitimation outcomes or even can create de-legitimation.

This article aims to fill these gaps in the current literature on ecosystems by discussing *how participants of entrepreneurial ecosystems, that engage in digital transformation, reduce their liability of newness*. This research question is further disentangled into the sub-questions of *(1) how an emerging digital transformation ecosystem is structured and (2) what legitimizing strategies emanate from the coordinated action of its participants*.

We investigate legitimacy-making in digital transformation by studying the participants of the emerging entrepreneurial ecosystem engaged in advanced air mobility (AAM) in Hamburg, Germany. While the idea of air mobility in cities goes back to the early 20th century (Cohen et al. 2021), the efforts towards AAM re-emerged as an entrepreneurial ecosystem in the 2010s based on digital technology. AAM is emblematic of the meshing of digital and physical materiality that takes place in digital transformations (Hinings et al.,

2018). Unmanned aerial vehicles (UAV), for instance, are additional sensors in the context of Industry 4.0 and create unique managerial and organizational practices (Agostini and Filippini, 2019). They reflect the idea of the Internet of Things (IoT) as a physical object that is enhanced by the use of algorithms and data-driven platforms for operation. UAVs also rely on advanced software for routing and traffic simulations as well as for automated piloting.

The studied ecosystem faces numerous *liabilities of newness* linked to that lack of legitimacy impeding the establishment as an entrepreneurial ecosystem that requires collective action. Technological goals of AAM ecosystems, such as the autonomous operation of drones or air taxis beyond the visual line of sight (Uyarra and Flanagan, 2022), touch upon a variety of socio-technical dimensions requiring legitimacy (i.e., legal, economic, technological, societal, regulatory, and political issues). The establishment of an AAM ecosystem requires thus not only new formal institutions and technological advancements and legitimacy to secure the legal and practical integration of AAM in a given place. The legitimacy of the entrepreneurial ecosystem of AAM is being driven by two distinct sectors; the established aviation sector and inputs from Industry 4.0-associated ideas such as artificial intelligence (Goyal et al. 2018; Fraske, 2022; Straubinger et al. 2020). Essentially then, entrepreneurs need a mutual understanding of the different tech development paths and change their mindset as AAM questions existing legal and operational paradigms, such as the re-definition of airspace and the co-existence of manned and unmanned aviation.

Empirically, this study uses qualitative research methods with an exploratory research strategy that allows analyzing the emerging ecosystem in Hamburg to advance this new mobility form. The empirical research is based on three types of primary sources. Initially, we conducted a network analysis to identify relationships among ecosystem participants. We then used expert interviews and participatory observations from applied research projects to gain deeper insights into the legitimacy-making strategies employed in the ecosystem's emergence.

The results of this study illustrate how ecosystem participants strategically define a system-level output for the early integration of AAM. The participants are institutionally dependent on legislative actors in this collective endeavor, who have a significant influence on the direction of socio-technical integration. In addition to business model innovation and legal responsibilities, there is a necessity to frame the narratives of feasible use cases for AAM, which are frequently shaped by skepticism and dystopian imaginations. Based on the empirical findings, we highlight two theory-based implications that inform the liability of newness and collective actions for digital transformations: Firstly, we consider a stronger reflection of existing hierarchies and spatial dependencies in emerging ecosystems. These dependencies are not only tied to policy interventions but also the exchange of different knowledge bases among entrepreneurs. Secondly, we challenge the conceptual assumption of the peripheral role of external actors (i.e., regulators). Our

analysis demonstrates that the awareness and proactive involvement of external actors are crucial factors in reducing the liability of newness of AAM.

The paper is organized as follows: Chapter two reviews the understanding of entrepreneurial ecosystems and introduces our framework regarding legitimacy emergence and the connection to the empirical field of AAM. Chapter three provides details on our methodological approach and the empirical sources. In the following, chapter four highlights the empirical findings with a focus on network analysis and the discursive and performative dimensions of AAM in Hamburg. Subsequently, we discuss our findings and conclude with the key contributions of this study.

2. Theoretical background: Entrepreneurial Ecosystems

Concerning the liability of newness of AAM, a special emphasis on the legitimacy process must be put on regulatory aspects as new socio-technical systems and technological arrangements require a fundamental change of formal institutions like rules and laws. The government can create a conducive economic and social environment for entrepreneurship, for example by adjusting laws and regulations (Stam and Spigel, 2016). Innovative technologies need to adhere to specific rules or policies (Harris, 2021). However, what if these regulatory frameworks are not defined yet and how do ecosystem participants address and impact the development of these frameworks themselves? In this regard, ecosystem literature often regards regulators as external actors, there are only a few insights on how the emergence of ecosystems is mutually tied to the development of new regulatory frameworks (Alaassar et al., 2022). Factors on the polity level, sector level, and organizational level have a profound effect on regulatory participation and organizational rationales like reputation can explain stakeholder engagement and how it is tied to legitimation (Braun and Busuioc, 2020). Moreover, legitimation on a regulatory level is essential to facilitate resource acquisition, help firms secure institutional support from governments in transition environments, and deal better with institutional uncertainties (Guo et al., 2014; Tina Dacin et al., 2002). In this case study, we use the framework of ecosystem legitimacy emergence by Thomas and Ritala (2022) as it provides a promising and holistic approach to cover different dimensions of legitimacy emergence and how they can be linked to different actor roles and identities within ecosystems. In the following, we define our theoretical understanding of entrepreneurial ecosystems and present the conceptual framework for our empirical analysis. Moreover, we enrich this theoretical endeavor with a perspective on the relationship between ecosystems, legitimacy, and new urban tech. Subsequently, we will introduce the case of AAM and sharpen the perspective on the current development and challenges.

Entrepreneurial ecosystems are “organic constellations of organizational participants that collectively cocreate system-level outputs associated with benefits for individual stakeholders within” (Autio and

Thomas, 2021). While ecosystems share certain principles with other organizational or spatial concepts like clusters, they are distinct in the understanding of how individuals organize their relations to create a knowledge flow. Entrepreneurial ecosystems are led by entrepreneurs themselves, in distinction to the top-down/policy perspective of clusters or regional innovation systems (Autio and Thomas, 2021; Stam, 2015). Thus, ecosystems should encourage entrepreneurs and other participating actors to take risks for funding and venture creation (Spigel, 2017). Rather than emphasizing the resources that a specific network or company contains, entrepreneurial ecosystems focus more on the ability of entrepreneurs to access these resources (Spigel and Harrison, 2018). Entrepreneurial ecosystems also put an emphasis on network relations that are defined by individual practices, which are not directly observable or easy to uncover. Moreover, they are industry agnostic, meaning that they highlight the importance of entrepreneurial knowledge that goes beyond industry-specific knowledge (Spigel and Harrison, 2018). Relevant examples would be experiences in building up an organizational culture, interacting with policymakers, or stakeholder management. This knowledge becomes particularly important in the emergence of industries, as they strive for new formal and informal institutions, such as lawmaking or the creation of legitimacy toward different actors and agencies. Hence, these aspects underscore the necessity to acknowledge the complexity and interrelatedness of ecosystems and their temporal dynamics (Lange and Schmidt, 2021).

Autio and Thomas (2021) highlight four characteristics that distinguish ecosystems from other organizational concepts: (1) Ecosystems aim at a *system-level output that* all participants collectively agree with. This outcome can be in the form of products, services, business models, or knowledge production. Moreover, participation is based on motivation and persuasion rather than on formal contracting. (2) The *heterogenous participants* are hierarchically independent and fulfill separate roles within the ecosystems. Unlike in value chains, the participants are volunteers without a predefined agreement on their specific role. (3) They are linked through *interdependencies*, such as physical interconnection, spatial proximity, or network effects. (4) The *coordination* mechanisms of the ecosystem must find a balance between change and stability. This process of coalignment also reflects the power relations between the participants.

Thus, emerging ecosystems not only rely on the aim of defining a system-level output but also to create common sense and stability within the ecosystem itself. While the concept of ecosystems was widely adopted in different disciplines, there is still an insufficient understanding of how new ecosystems emerge (Thomas and Ritala, 2022) – including the acquired legitimacy, such as social acceptance, plausibility, and credibility beyond their material resources and capabilities (Suchman, 1995). This study focuses on ecosystem legitimacy emergence with a special emphasis on the importance of emerging regulations and legal frameworks.

2.1 Ecosystem legitimacy emergence

This article uses Thomas and Ritala's (2022) framework of ecosystem legitimacy emergence as the key analytical foundation. Thomas and Ritala (2022) conceptualized ecosystem legitimacy emergence as a collective process composed of three different ecosystem legitimation processes: (1) discursive legitimation processes, which promote ecosystem acceptance and comprehensibility, (2) performative legitimation processes, which demonstrate the viability of the ecosystem, and (3) ecosystem identity construction, comprising the emergence of a mutual understanding of what the ecosystem is about and what it seeks to achieve, and how it seeks to do this. Emerging ecosystems must therefore be perceived as legitimate not only by the ecosystem participants but also by other actors in the broader environment that entangle the development (Thomas and Ritala, 2022).

To analyze the collective action for legitimacy emergence in ecosystems, the key actors within a given ecosystem must be identified and disentangled. Ecosystems consist of diverse types of legitimating actors. The *orchestrator* is the focal point of the ecosystem and advocates its value propositions and provides crucial resources for other actors (Thomas and Ritala, 2022). An orchestrator thus shapes the goals, identity, and design of an ecosystem (Gulati et al., 2012). *Complementors* provide complementary products, services, or inputs that contribute to the value proposition (Jacobides et al., 2018; Shipilov and Gawer, 2020) and need to build legitimacy for their own contributions within the ecosystem (Thomas and Ritala, 2022). *Users* legitimize ecosystems through their adoption of the value proposition, especially large and powerful users who can contribute to the legitimacy of an ecosystem (Thomas and Ritala, 2022; Tushman 1992). External actors in the ecosystem can be the media, financial analysts, competitors, or regulators. Especially regulators can play a vital role in enforcing standards for new technological settings (Garud et al., 2022). Table 1 provides a summary of the main processes for discursive and performative legitimation and the ecosystem actors who perform each type of action.

As the stated goal of this paper is to unveil how legitimacy emergence in the context of AAM can be regarded as a performative and discursive act. The next chapter should provide insights in the current development of AAM and the liability of newness of this new mobility form.

Process	Ecosystem role	Explanation
Discursive Legitimation		
Framing	Orchestrator	Framing a vision that identifies why the ecosystem should be preferred to alternatives. Motivating others to act. Use of familiarity or public interest to influence venture funding.
Sensemaking	Complementor	Social learning: a participative process where ecosystem participants develop and share insights, categorize the components of ecosystem value proposition, and form shared views of what is feasible and desirable.
Positioning	Users	Evaluating the ecosystem is a cognitive process. Perceptions of user value can be economic, functional, emotional, and symbolic.
Recognizing	External actors	External actors can be the media, analysts, regulators, or others from wider society. Actions can include entering the general lexicon; referencing in art; winning awards; and the release of books, magazines, academic or medical research.
Performative Legitimation		
Strategic Action	Orchestrator or complementor	Ecosystem-specific investments into resources and technology design. Governance design: the establishment and application of rules that control activity within the ecosystem, including efforts to establish norms and procedures to solve collective action problems that may arise.
Value Realization	Orchestrator or complementor	Ecosystem as a collective, generating revenue. Constant adaptation by orchestrators and complementors to reach the state of value realization.
Adoption	Complementor or user	Complementors can facilitate adoption in many ways, such as by participating and delivering skills and resources. Adoption by powerful users, such as governments or powerful organizations.
Intervention	External actor	Financiers, such as venture capitalists, public offerings. Regulators such as local authorities, the legal establishment of standards and rules. External interventions can be crucial for the ecosystem to scale and ride out the negative costs of the transitional period.

Table 1: Performative and discursive legitimation dimensions, based on Thomas and Ritala 2022.

2.2 The case of advanced air mobility

Besides the general distinction between drones and air taxis for passenger transport, AAM encompasses different concepts, vehicle types (vertical or short-runway take-off), and functionalities that differ in their propulsion, design, capacity, range, autonomy, and compatibility with existing infrastructure and operational systems (Cohen et al., 2021; Thipphavong et al., 2018). Hence, unmanned aerial vehicles (UAV) must be embedded in an overall unmanned aircraft system (UAS), which refers to mandatory

communication, artificial intelligence, the internet of things, or big data tools (Cohen et al., 2021). While small drones generally have a lower entry barrier regarding their socio-technical integration in comparison to air taxis, the discourses, limitations, and legal obligations of both technological strands share several similarities.

Regarding the liability of newness of this new mobility form, certain issues become apparent. The value proposition of this new mobility form is still unclear, as there are no established business cases yet and the existing start-ups are heavily dependent on venture capital. The development of UAVs is still very much dependent on the actual application scenario in which they should operate. Moreover, the integration into the existing airspace (Bauranov and Rakas, 2021), modal split and welfare aspects (Ploetner et al., 2020), ecological and noise emissions (Vascik and Hansman, 2018), as well as the social acceptance (EASA, 2021a) are crucial factors for a broad integration. Far-reaching scenarios, such as the use of drones in last-mile logistics, have become unlikely due to these barriers, at least in the near future. Therefore, companies increasingly expand their urban perspective to more specific use cases, e. g. critical-time logistics (healthcare, maintenance, and repair), regional logistics (urban-rural connections), or business-to-business deliveries (Fraske, 2022). Nevertheless, only a few applied projects and practical experiences exist. Thus, the long-term sustainability of this innovative development remains unclear, both economically and socially (Cohen et al., 2021; Biehle, 2022). Regarding passenger transport, in 2020 and 2021, investors put over 5 billion $ into the emerging sector. Six companies alone account for 4.6 billion $, including the German companies Volocopter and Lilium (Shaposhnikov, 2021). As an industrial report reflects, this is ten times as much as in the ten years before and stresses the risk that the valuation runs out the technological maturity too fast (Shaposhnikov, 2021). Moreover, the air taxi discourse accounts for higher media coverage, including the plans of Volocopter to initiate the first air taxi routes in Europe at the Olympic Games 2024 in Paris. Subsequently, air taxis greatly accelerated the narratives toward AAM, raising the question if this development overwhelms smaller drone developers, or whether they can potentially benefit from it (Fraske, 2022).

The regulatory embedding of this new mobility form accelerated with the publication of two proposals by the European Union and the European Aviation Safety Agency (EASA): Firstly, a proposal that should motivate municipalities to engage in the development of AAM and organize the necessary socio-technical changes on a local scale (UIC2, 2021). In Germany, Hamburg was the first city that adopted this idea in 2017 and founded a network organization to bring companies, researchers, and city representatives together. Secondly, the EU provided a proposal for the integration of “u-spaces” which should enable the practical connection of manned and unmanned aviation in defined air space and provide platforms for the

management and operation of automated flights (EASA, 2021b). While the EU takes a pioneering role in formulating legal frameworks, practical competencies are deliberately shifted to the national and local scale.

3. Methodology

This study is based on an empirical investigation which is based on the following methodological steps.

Firstly, we carried out a network analysis to delimit the entrepreneurial ecosystem and to contextualize our case study. In this aim, we collected information through desk research by identifying the actors in AAM in Hamburg based on project websites and documents. More precisely, we started with the accessible information on the existing AAM network organization "Windrove" as well as former and ongoing (research) projects and network organizations. From there, we use snowball sampling to identify additional projects related to AAM development and therein involved organizations. To build a network depicting the ecosystem's collaboration patterns, we consider projects and the involved organizations as nodes and project involvement, consortium membership, and company ownership as direct ties. We then classify based on publicly available information. Numerous organizations in the ecosystem are hybrids that lie at the intersection of typical organizational typologies. To overcome definitional problems with hybrid organizations (e.g. government-controlled companies, long-term public-private partnerships), we define the nodes in the context of this case study regardless of their formal status. State-owned companies (i.e. companies in which different levels of government hold at least 50% of shares), for instance, are classified as companies if they are primarily engaged in market activities (e.g. HHLA which commercially manages harbor logistics) or as governmental organizations, if they have regulatory powers (e.g. the DFS which regulates air travel and flight security whilst formally being structured as a private state-owned company). In other words, we classify organizations as government authorities if they have regulatory power over a segment of economic or public life regardless of whether they are a ministry or a public-private partnership.

Secondly, we interviewed a total of 22 experts that are related to the development of AAM. The interviewed entrepreneurs involve a heterogenous set of unmanned aerial vehicle (UAV) developers, system- and service providers, and consulting companies. Moreover, we addressed public-related actors like operation agencies, network organizations, and municipalities. Table 2 provides an overview of all interviewees including their sector of activity and location. Most actors are either based in Hamburg itself or have direct ties to AAM development in Hamburg by participating in networking activities or research projects. As the AAM sector in Germany is still emerging, we also included insights from actors outside of Hamburg to broaden our view on the overall development. We identified and selected interviewees through our network analysis, project insights, websites, and snowball sampling. The interviews were semi-structured and

afterward analyzed and coded with the software Maxqda based on the categories of the theoretical framework.

Thirdly, through the participatory observation method, we draw on internal insights from three AAM research projects in Hamburg, including our own research during the project running time as well as participatory observation in workshops. Each project has a different thematic focal point and provides a specific understanding of the local stakeholder network. The project “Medifly” deals with critical logistics by using cargo drones for medical transport between hospitals, such as organs or tissue samples. It includes different participatory methods to analyze the social acceptance of AAM in Hamburg and differentiates between the acceptance levels of different use case scenarios. The second project “i-LUM” (innovative airborne urban mobility) analyzes the development from different methodological, systemic, and knowledge foundations to evaluate the feasibility, create a holistic simulation tool, and ultimately describe future scenarios of AAM in Hamburg. Our research focuses on urban studies and regional economics of AAM, especially regarding ground-based infrastructure and innovation dynamics. The last project “LUV” addresses the u-space proposal of the EU Commission. It provides recommendations for future enhancement of the current state and how the ideas can be transferred into the local and national context. The project also involves the main public authorities to discuss and evaluate potentials for the operation and legal frameworks.

Sector/role of the interviewee	**Local actor (Hamburg based)**	**Local-related actor (ties to Hamburg)**	**Non-local actor (No ties to Hamburg)**
Company			
UAV developer	#1	#5, #9	#7, #16
Service provider	#4, #6, #10, #13		
Consultant	#8		#11, #12
Government/Authority	#14, #15	#2, #3, #17	
Networking organization	#18	#19, #20, #21, #22	

Table 2: List of interviewees.

4. Emerging AAM ecosystems in the case of Hamburg

Hamburg became the first region in Germany that addressed the EU initiative for AAM (UIC2, 2021) and formed the first German AAM model region “Windrove" in 2017. Windrove is part of an aviation cluster organization and is closely linked to the existing knowledge base of the aviation industry in Hamburg. Today, the networking initiative has over 50 members with more than 90% of them located within the

metropolitan region of Hamburg. While Hamburg has a broad regional background in associated sectors like aviation and logistics, most key players in the emerging air mobility market are located in the south of Germany, such as Airbus Urban Mobility, Volocopter, or Lilium. Therefore, start-ups and small and medium-sized companies represent the AAM development in Hamburg. Moreover, local research facilities engage with the topic increasingly.

In the empirical analysis, we focus on two aspects: Firstly, describe and structure the AAM ecosystem in Hamburg based on social network analysis. Secondly, analyze the performative and discursive legitimation processes based on the theoretical framework.

4.1 Mapping and identification of actors

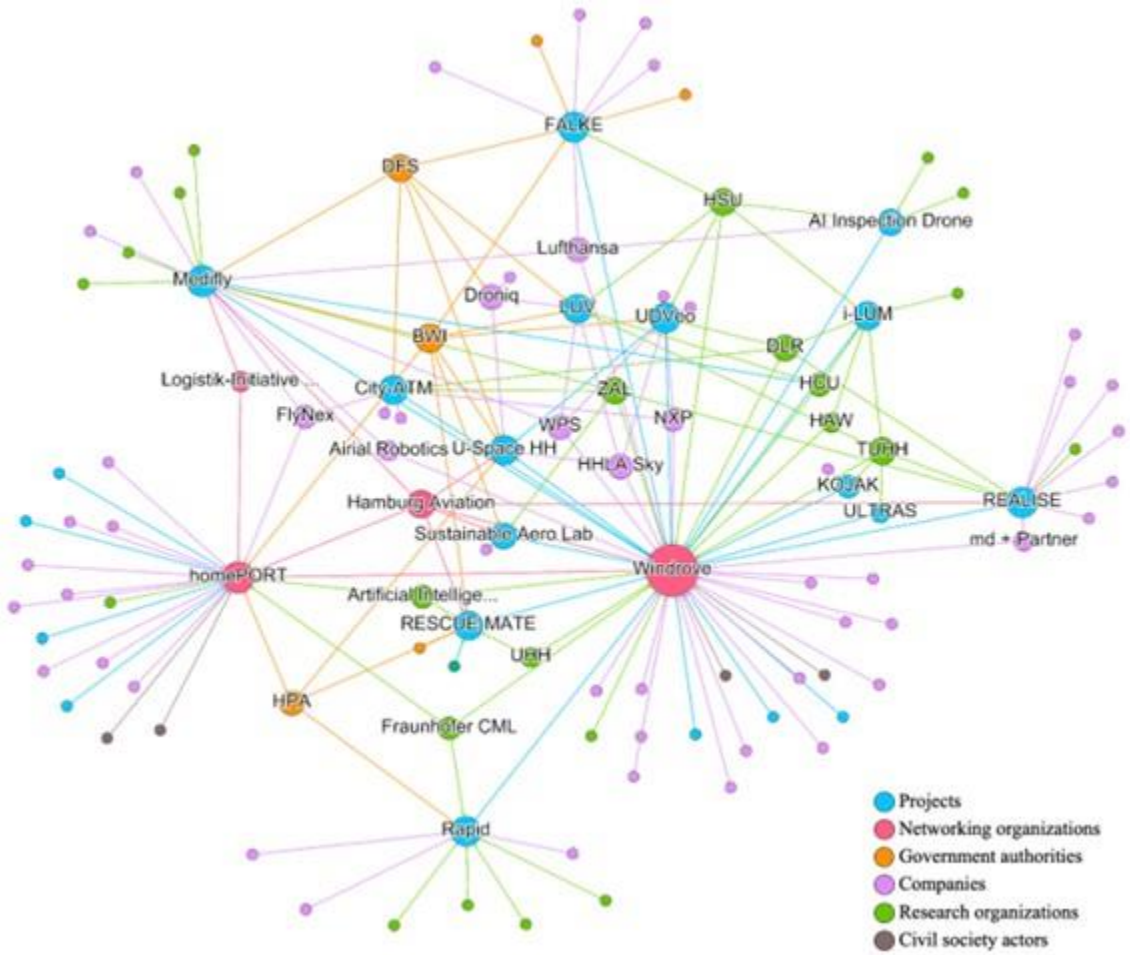
As our network analysis initially centered on Windrove it naturally gives this network organization a relatively high prominence in the collaboration network. Nevertheless, the network graph reveals (also the other) key characteristics of Hamburg's emerging AAM ecosystem.

For one, the collaboration network highlights the decentralized character of the ecosystem. Even if the (in-)degree distribution of all nodes in the network highlights the assembling (and potentially orchestrating) role of large project consortia, and of network organizations and clusters, such as Windrove, the ecosystem has no hierarchical structure. While some projects and network organizations, such as Hamburg Aviation, connect numerous actors to each other, the projects of the ecosystem are connected to each other via government agencies and research actors notably from Hamburg's Authority for Economics and Innovation (BWI), the port authority (HPA), and all of Hamburg's major universities (TU, HSU, UHH, HTW and HCU). The Authority for Economics and Innovation (BWI) is the actor with the most widespread participation by being directly part of eight of the 20 projects in the ecosystem. The out-degree distribution highlights the role of Hamburg-based public authorities and Hamburg-based universities in the emergence of an AAM ecosystem. At the same time, only a few corporate organizations participate in more than one project or network and only 8 of 54 companies of the ecosystem have more than one direct connection in the network. Moreover, only 3 companies figure among the 10 most engaged organizations despite over 60% of the ecosystem's organizations being companies (HHLA Sky; Lufthansa, and Workplace Solutions). Key companies at the national level (e.g., Lilium or Volocopter) do not directly engage in the projects of Hamburg's AAM ecosystem. The network graph (Figure 1) visualizes the central role of government authorities, universities, and industry representatives such as industry interest groups as central stakeholders in the emerging ecosystem.

For another, while the majority of actors in the ecosystem are Hamburg-based, over 40% of involved organizations come from other parts of Europe. While we define Hamburg's AAM ecosystem as based

around the AAM projects taking place in Hamburg, the ecosystem is not limited to Hamburg-based organizations. Of the 89 distinct organizations that participate in 20 projects of the ecosystem, 51 organizations (57%) are Hamburg-based[1]. However, while a large proportion of organizations in the ecosystem is not from Hamburg, the most well-connected organizations are Hamburg-based. While Hamburg-based organizations have an average of 2.04 connections in the network, organizations from outside Hamburg only have 1.26 connections on average. Nevertheless, organizations from outside Hamburg include key regulating bodies such as the DFS (i.e., Germany Flight Security Agency) and Droniq as a u-space service provider.

Figure 1: Network graph of AAM in Hamburg, own elaboration.



[1] We counted some organizations as Hamburg-based if they have a significant office in Hamburg (e.g. Airbus)

Even if based on directed links, still this network graph fails to properly depict the diversity of the relationships among the actors; which can range from joint membership in a networking organization to long-term project collaboration. Nevertheless, this graph highlights the ecosystem-like nature of the emerging AAM sector which is composed of heterogeneous actors who appear to be loosely coordinated. The governmental authorities (BWI; HPA), networking organizations (notably Hamburg Aviation, Windrove), researchers at Hamburg's major universities and research institutes (TU, HSU, UHH, HTW, HCU, and Fraunhofer CML), and a small group of outstandingly engaged companies (HHLA Sky; WPS; Lufthansa, FlyNex; NXP, Droniq) appear to be the key actors that coordinate in different projects to advance the AAM sector in Hamburg.

4.2 Ecosystem legitimacy emergence of AAM

In the following, we reflect on the discursive and performative dimensions of the legitimacy emergence of AAM in Hamburg. Discursive legitimation resembles the current discourses and narratives surrounding the development of AAM to promote the comprehensibility of the ecosystem, both inside and outside of the metropolitan area. Performative legitimation covers the practical outcomes of the strategic actions by the involved actors to strengthen the viability of the ecosystem.

4.2.1 Discursive legitimation

While the *framing* of an ecosystem considers the emergence of a vision and motivates others to act, the most critical issue is the lack of an orchestrator who conducts these actions in Hamburg. So far, all involved actors are primarily concerned with understanding each other´s competencies and getting to know the ecosystem itself. While the interviewees agree on the importance of coordinating actors and forerunners and some actors provide orchestrating activities, no actor so far provides a clear framing of the local ecosystem. This is mainly because many legal issues are still under negotiation and future use cases are not clearly identified yet. Moreover, there is still a blind spot on the amount that urban actors ultimately want to invest in these new AAM services. As a potential orchestrator, the local network organization Windrove receives ambiguous feedback from the other actors. While some highlight its impact on the discursive processes as important for knowledge transfer and initiating projects, others criticize the lack of proactive engagement. One CEO highlights that he is "strongly connected to the business feeling here in Germany, but there is a lack of willingness to communicate (Interview #10)" while a software developer indicates that "Hamburg is well known for its aviation industry, but there is no label behind the whole drone topic […] there must be a main coordinator to manage all the concerns (Interview #13)." Besides connecting companies, Windrove itself is primarily concerned with advocating the interests of the municipality on higher policy scales. Rather than competing with other existing AAM model regions in Germany, it is more

important to collaborate regarding the emergence of legal frameworks and communicating regional interests to the national authorities.

While the ecosystem misses a clear framing in its current state, *sensemaking* is characterized by a vital discussion by the complementors on what solutions are actually feasible and can lead to a value proposition soon. Companies highlight three main concerns: creating certification and safety standards, receiving funding, and raising acceptance for scalable business cases. This involves the different perceptions of cargo and passenger transport. As the use cases and discourse differ greatly between these two main application areas, most drone developers have a critical stance toward air taxi development since it creates high expectations, and media coverage, and involves a greater amount of venture capital. Because of this, and due to the absence of air taxi developers in Hamburg, the local agencies address this topic more reservedly and focus instead on industrial applications, such as medical transport or port logistics. As the market is very untransparent so far, most companies stress that they have no feelings for competitors yet and are primarily focused on their internal developments, as a CEO in UAV development exemplary states: "My biggest competition is to do nothing [...] many actors in the current market do not know what the others are actually doing (Interview #9)." The local agencies in Hamburg put a strong emphasis on two aspects: Firstly, screening current developments and trying to build up a diverse entrepreneurial community, and secondly, the exchange with other AAM regions in Germany and Europe. This inter-regional cooperation should help to learn from each other's project experiences as well as reflect on the current legal frameworks and adaptability of AAM from different perspectives.

Regarding the *positioning* of AAM, it can be highlighted that the embedding of use cases requires not only social acceptance but also growing harmonization and trust-building between the industry and involved authorities. The current state is still in a very early stage, as there is simply no broader user base, and most companies are dependent on funding or venture capitalists. Most use cases can be described as experimental spaces, where certain application areas are being evaluated in research projects. However, these temporary projects did not lead to long-term outcomes in terms of value proposition yet. As a local operator states, "you cannot always ask a hundred people first, AAM must be tested in practice […] you cannot sugarcoat things, you need to deliver clear arguments (Interview #15)." This also refers to the public-private nature of some key actors, as they need to set new legal frameworks and, at the same time, have a commercial interest. The companies are also aware of the uncertainty regarding their actual target group, which is why the focus in technology development often lies in providing a scalable solution that is applicable to different use cases.

Recognizing the AAM ecosystem in Hamburg by external actors must be distinguished between political and industrial recognition. While Hamburg is regarded as an important industrial location by companies with many potential partners across the entire value chain, other AAM actors in Germany (Interview #19 - #22) often refer to Hamburg as a forerunner in strategic development, especially in the forethought of u-spaces as well as entrepreneurial networking. For instance, the Medifly project received critical acclaim in the local and national political discourse but was received with restraint from the economic or operational side, as it did not really contribute to technological development. However, far-reaching milestone projects are still missing, such as the Volocopter air taxi routes during the Olympic Games 2024 in Paris. Moreover, some companies (Interview #1, #5, #9, #10) highlight the importance of cross-sectoral embedding and global knowledge exchange as more crucial than their local embedding. As a CEO indicates, "it (the AAM development) is too imbalanced here in Germany and Europe to evolve an entire sector […] no one is going to be successful in urban air mobility thinking about their country alone, winning players are global players (Interview #10)."

4.2.2 Performative legitimation

Strategic action is the main performative challenge for all involved actors and stakeholders in the current development of AAM in Hamburg. This includes both investments in resources and technology to develop scalable and unique technological solutions as well as governance design to provide sufficient legal frameworks for operation. As for technological developments, companies highlight automation as the key issue. This stresses that AAM is a digital transformation that is not only reliant on conventional aviation knowledge but requires input from robotics and artificial intelligence for autonomous flying. Besides the vehicle itself, there are many start-ups that deal with associated supporting technologies for operation, such as geographic information systems for weather and route simulation, ground-based infrastructure for take-off and landing, or integration of AAM in traffic management. Most companies are also dependent on either project funding or other loose relations with big corporations like Airbus. However, only a few companies have long-term relationships with big corporations in AAM development from other regions or internationally. Therefore, companies focus on reducing the complexity of AAM and identifying low entry barriers for applications. Ties to other entrepreneurs in the ecosystem exist primarily for knowledge exchange and project acquisition. Windrove provides different activities to enforce this exchange, such as individual consultation or thematic working groups. The actual impact on the ecosystem is, however, hardly measurable. While there are a couple of applied projects that directly evolved out of networking activities, most opportunities are not discovered by strategic action. As described by a CEO, "most cooperations are driven by the opportunity itself, recommendations, and informal networking […] There are some strategic components, but most of it is coincidence in the end (Interview #9)." Therefore, there is a need for

intermediary actors that can bridge the different focal points and knowledge bases. These could be the state-led operators or Windrove, but sustainable and stable growth of the ecosystem has yet to evolve.

In terms of ecosystem *value realization*, there are only a few use cases that succeeded in market creation so far. Those use cases are primarily limited to individual industrial applications. As a local operator highlights, "port- and intra-logistics play a big role as potential customers, but the solutions must be adapted for every case individually […] I would say, 50% of the solutions are standardized, the other half is use-case specific (Interview #14)." Practically all actors agree that for a broader market creation that also involves urban logistics or passenger transport, the legal frameworks and social acceptance are not sufficient yet. This underlines the insecurity felt by all actors that there is no clear understanding of at what point AAM applications could ultimately create revenue. This also leads to the fact that some actors must take higher risks or engage more in practical experimentation than others. Ecosystem actors with different sectoral backgrounds, such as energy management, are more resilient to a potential failure of AAM, as it is only a minor aspect of their portfolio.

The *adoption* of AAM in Hamburg is closely tied to applied research projects that provide space for experimentation. This involves both the direct participation of companies to deliver specific skills or resources into applied projects, as well as acting as an associated partner to benefit from the knowledge insights. In this regard, the ecosystem participants are especially interested in exchanging with the local and state authorities, as they will ultimately be the key actors to sensitize for the successful integration of AAM in the metropolitan area. National authorities and public-private operators also play a crucial role in most projects, as they can act as a bridge between the political and commercial sides of the development. Although closely tied to the discursive positioning of the topic, most projects did not lead to a long-term outcome. However, they can provide a necessary resource for human capital and unveil important stakeholders within the ecosystem. External actors, such as authorities and research facilities, act as users in this regard and can provide crucial knowledge about the current state of the technology and potential gaps in the socio-technical embedding.

Regarding the *intervention* of external actors, it becomes clear their role is of high importance in this early stage of development as they provide particularly relevant legitimation strategies. Three key actors that have a strong influence on the current ecosystem legitimacy emergence are the EU/EASA, DFS (German air traffic control), and venture capitalists that engage with this technology. The EU pushed the topic of AAM greatly in the past years and encouraged cities to engage with the topic. While the general perception of the EU proposals is positive, there is also criticism of the overcomplicated bureaucracy in Europe and especially in Germany. Companies refer primarily to the certification processes and the embeddedness in

the existing air traffic. As a CEO states, “the DFS must fundamentally rethink their role with the flight operations of unmanned vehicles, the management of the platforms, bureaucracy […] Then on the second level are the state agencies: the integration of pilot projects, everything is just way too slow (Interview #1).” While companies criticize the slow embedding, agencies highlight that there are still essential technological gaps. This includes safety issues such as emergency landings, but also the routing and positioning of the flight trajectories. Commercial actors would often overlook these issues or leave them out of the overlaying discourse. The liability of newness is mitigated by acquiring funding, which highlights the trust of venture capitalists in the value proposition. However, this underscores the necessity for an efficient marketing and public relations strategy, as big investors remain crucial for entrepreneurs in this emerging field (Interview #1, #4, #9).

4.2.3 Ecosystem identity construction

The emergent ecosystem so far lacks a clear identity, as discursive and performative actions are not always in a positive mutual relationship, but partially counteract each other. This becomes apparent at the example of the drone vs. air taxi discourse. While air taxis account for the majority of venture capital and media coverage, small drone developers highlight the risk and bias of these narratives. They fear that negative experiences and non-acceptance of air taxi development may also affect the drone sector (Interview #1, #9, #13). Thus, expectations of AAM can elude technological maturity and hinder performative actions that aim at different use cases. Moreover, the perception of forerunner projects can differ greatly among different participants, as they can rarely fulfill everybody's interests and intents. The only internal identity aspect that can be highlighted in Hamburg, in contrast to other AAM model regions in Germany, is the strong linkage to the existing aviation industry. However, this bias also involves potential risk, as many actors clearly emphasize the importance of combining multiple knowledge bases. This makes coordinating activities along the model regions of AAM an even more important necessity to overcome a potential discursive bias within the region and exchange experiences about the outcome of performative actions.

5. Discussion

To overcome the liability of newness, participants must not only reflect intra-organizational and intra-ecosystem questions, but they are reliant on addressing a wider audience and higher policy scales to strengthen their claims. The case of AAM in Hamburg offers us insights into the local dynamics of ecosystem legitimacy emergence in the context of digital transformation, which is surrounded by broader socio-technical discourses, industrial development, and policy debates. While the involved actors highlight a lack of transparency and a great uncertainty regarding the overall development as main issues regarding

their liability of newness, all can agree on a collective system-level output: the goal to lower entry barriers and allow the practical operation of AAM within defined legal frameworks. The coordination mechanism of the ecosystem must still find a balance between change and stability, primarily because of the absence of an orchestrator. While the participants are very heterogeneous in terms of their innovation development, most share the same industrial knowledge background with a focus on the aviation sector. The most apparent blind spot can be highlighted regarding the interdependencies of the ecosystem participants. While some are connected through Windrove, applied projects, or spatial proximity, there are still several actors who criticize the missing engagement by the policy side and do not feel embedded at this point of development. Only a few participants have a direct impact on shaping regulations or maintaining connections to key actors who do so. Small companies focus more on technological progress and dynamic business models instead of engaging with the system-level output, as they do not see themselves in the position to enforce a necessary change in legal and operational matters.

The integration of urban tech like AAM is a highly cross-sectoral development, where established networks overlap and stakeholders from different fields must address different knowledge bases. This recombination of existing networks and knowledge backgrounds during digital transformation creates, on the one hand, a thriving environment for research, spillover effects, and experimentation; on the other hand, it requires complex stakeholder management that requests coordination among different policy scales. This aspect is exemplified in the debate between drones and air taxis. While the strategic actions and knowledge background so far focus on drone development, passenger transport is a key factor for the emerging legitimizing narratives surrounding AAM. There have been attempts to address this matter, but authorities remain hesitant regarding the practical embedding of passenger transport with AAM. Besides the high entry barriers, this is mainly because a lot of these discourses are still regarded as dystopian futures, as air taxis do not have the reputation for providing benefits to the broader society. Drawing from the empirical case, we highlight two main theoretical implications that can contribute to a better empirical engagement and understanding of how ecosystems unfold and how this emergence is intertwined with other processes: firstly, the importance of existing hierarchies or legal responsibilities in the empirical field; secondly, the assumption of a peripheral role of external actors without orchestrating activities.

One aspect regarding the creation and early direction of the ecosystem lies in the analysis of existing hierarchies that impact or guide the development. How do ecosystems co-evolve with other organizational and spatial phenomena like clusters or regional innovation systems? And can organic constellations like ecosystems establish without any hierarchical dependency beforehand? While there is enough evidence to support the claim for an emerging AAM ecosystem in Hamburg, there are strong hierarchical relations to engagement by the EU as well as the existing aviation industry in Hamburg. Hence, these observations clearly emphasize the need for a more process-oriented perspective on ecosystems (Spigel and Harrison,

2018). Besides the theoretical and conceptual linkages of cluster/regional innovation systems and ecosystem literature, there is a need for a stronger empirical engagement on how these concepts are interrelated and can mutually benefit or hinder each other.

Building on these findings, we want to question the rather peripheral role of external actors such as regulators in the conceptual literature. The AAM case shows that public-private actors often have a double role in the sense that they are both embedded within ecosystems but still have an authority function within the state. Hence, they provide some orchestrating activities, but can still be regarded as an external actor that has the obligation to shape regulations (e.g., DFS). This would call for a more institutionalist perspective on ecosystem emergence. As these state-owned companies are quite common in the transport sector, for instance in the German railway system, there needs to be a more differentiated perspective on how these actors are embedded within ecosystems and what their effect is on existing hierarchies. This raises the following future research questions: How are regulators/external actors shaping and limiting the potential of emerging ecosystems? To what extent do they provide orchestrating activities such as framing or value realization? The mutual relation between acting as an orchestrator and regulator at the same time also raises the question of how the top-down directives from the policy side can counteract the collective and voluntary ideas of ecosystems.

6. Conclusion

The goal of this article is to provide insights into the legitimacy emergence of ecosystems that point to the success of digital technologies. For this purpose, we analyze the ecosystem legitimacy emergence in the case of AAM in Hamburg. With our insights from network analysis, expert interviews, and project participation, we identify key actors of the emerging ecosystem and present the discursive and performative legitimation strategies of the involved participants to reduce their liability of newness. The case of AAM in Hamburg shows us that while there are local dynamics and a collective system-level output, non-local structures greatly influence the overall development. This circumstance is reflected particularly in the dominant role of state-owned companies, which have a decisive impact on the emergence of the ecosystem. In this regard, they serve as regulators and provide orchestrate activities at the same time. This not only questions the bottom-up nature of ecosystems but also shows how strongly processes of digital transformation depend on existing socio-technical systems and their institutional structures. AAM is surrounded by multiple discourses and uncertainties, where independent ecosystems can help strengthen local and civil interests. This is exemplified in the distinction between drones and air taxis that, despite their technological differences, share many narratives, which makes it more complex to develop a collective

understanding of the ecosystem identity. However, the participants wish for a leader/mediator who can fulfill this missing role of an orchestrator.

The case study also reflects the temporal and spatial dynamics of digital transformation. As for AAM, the current system-level output clearly highlights the necessity for a future event to happen, namely defining a clear legal framework for operation. Once this legal framework is established, it is reasonable to expect that the structures, as well as the competition within and between emerging ecosystems, will be renegotiated. Therefore, future studies must focus on these temporal and spatial boundaries of digital transformation and also consider the various power structures in which the emerging technologies are embedded. In particular, this accounts for cross-sectoral interdependencies between existing sectors like aviation and growing technologies like artificial intelligence. This diversity creates a high potential for innovative development, but it also raises barriers that must be overcome in order for these new approaches to be adequately legitimized.

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Appendix

Interview guideline (Paper 2)

The following guideline for the interview is not a strict questionnaire but just an orientation for the topics I want to discuss. The focus may vary for every person I want to speak with, depending on their positions, functions and priorities. The interview should last about 45 minutes. The data will be treated confidentially and anonymously.

1. What position are you in and what are your responsibilities and tasks there?
2. What is your connection to the logistic sector in Barcelona?
3. In what projects or technology developments are you currently involved in some way?
4. How would you describe and rate the current situation of urban logistics in Barcelona?
    a) What aspects are positive?
    b) What aspects are negative?

5. What are the most important stakeholders and organisations in the city logistics of Barcelona?
6. Have you heard of the development of the apps “Name1” and “Name2” to regulate economic traffic and manage parking areas? (If no, skip to question 11)
7. How were you involved in the development of the apps?
8. What was the origin of the idea?
    a) Are there overlaying processes that supported this development?
    b) Were there central actors in the city who supported the development? How?
    c) Were there new actors who enforced and emerged during the development?
9. What is the current state of the apps and their implementation within society?
    a) Criticism?
    b) Measurable Effects?

10. How important were the local circumstances in Barcelona for the development? Would it be transferable to other cities?
11. What are other current innovations in the IoT and logistics sector that are transforming the city logistic in Barcelona?
12. What would be necessary improvements in the regulation of the economic traffic in Barcelona in the future? How can the apps support that development?
13. If you could install an app-based regulation system in Barcelona again, would you do something different?

Interview guideline (Paper 3 & 4)

For companies (English):

The following guideline for the interview is not a strict questionnaire but an orientation for the topics I want to discuss. The focus may vary for every person I want to speak with, depending on their positions, functions, and priorities. The interview should last about 45-60 minutes. The insights will be treated confidentially and anonymously and will only be used for scientific purposes and publications.

1. What position are you in and what are your responsibilities and tasks there?
2. How would you describe the current development phase of your company? (e.g. main challenges)
3. Please describe the intention and your role during the foundation/evolution of the company. (*What short-term opportunities did you see? What is the long-term goal?*)

4. Please explain the general functionality and purpose of your technology or solutions.
5. What role does the transport and logistics sector play for you? How do your solutions/innovations contribute to the future transport systems?
6. What are unique elements of your technologies? (*e.g. patents*)
7. How is the competition in your market segment? How many comparable technologies/approaches exist?

8. What are the main skills and capabilities that entrepreneurship in your field needs to provide?
9. What are the main risks, challenges, or barriers for your development?
10. Which legal frameworks, rules, or working routines must be adapted for the integration of your technology? Who is affected by these changes?

11. How would you describe or rate the importance of your local networks and place-based leaders?
12. What are your most important national and global partners for your development? (*Industry, "big players", funding programs, etc.)*
13. How important is it for your development to enter different geographic locations with your technology in its current state?
14. In retrospective, what was the most important moment or process that supported or hindered your development? What would you do differently if you could tackle these challenges again?

For policy actors/cluster managers (German):

Der folgende Leitfaden für das Gespräch ist kein strenger Fragebogen, sondern eine Orientierung für die Themen, die ich besprechen möchte. Die Schwerpunkte können je nach Position und Aufgabenbereich der Interviewten variieren. Das Gespräch sollte etwa 60 Minuten dauern. Die Erkenntnisse werden vertraulich und anonym behandelt und nur für wissenschaftliche Zwecke verwendet.

1. Welche Position haben Sie inne und was sind Ihre Verantwortlichkeiten und Aufgaben dort?
2. Wie würden Sie die aktuelle Entwicklungsphase Ihrer Initiative beschreiben? (z. B. *aktuelle Herausforderungen*)
3. Was waren die initialen Zielsetzungen der Initiative? Was ist das langfristige Ziel?
4. Bitte erläutern Sie den primären Zweck und die Absichten ihres Netzwerkes.
5. Welche proaktiven Maßnahmen bieten Sie an? (*Förderinitiativen, Beratung, Netzwerktreffen etc*.)

6. Wieviele Mitglieder haben Sie? Welchen Background (*Sektor, Unternehmensgröße, Standort*) haben diese? Wieviele waren vorher schon im übergeordneten Netzwerk?
7. Wie adressieren oder identifizieren Sie potentielle neue Mitglieder? Wie viele kommen auf Sie zu?
8. Wie verteilt sich die Aktivität der Mitglieder in Ihrem Netzwerk?
9. Welche Projekte oder Kooperationen konnten praktisch bereits initiiert werden?
10. Welche Themen werden besprochen? Welche Probleme werden von den Unternehmen kommuniziert?
11. Wie adressieren Sie diese Probleme?
12. Welche Standortvorteile sehen Sie in Ihrer Initiative? (*vor Ort und regional/überregional*)
13. Wie würden Sie das aktuelle Entwicklungspotential und Umfeld für UAM in Deutschland beschreiben?
14. Wie ist ihre Beziehung zu den anderen Clustern in Deutschland? Was sind gemeinsame Aufgaben? Wo liegt ggf. ein Konkurrenzgedanke?

15. Welche rechtlichen Rahmenbedingungen oder Regeln müssten für eine erfolgreiche Umsetzung von UAM verändert werden? Wie adressieren Sie diese Notwendigkeiten?
16. Was war rückblickend der wichtigste Moment oder Prozess, der Ihre Entwicklung gefördert oder behindert hat? Was würden Sie anders machen, wenn Sie diese Herausforderungen noch einmal angehen könnten?